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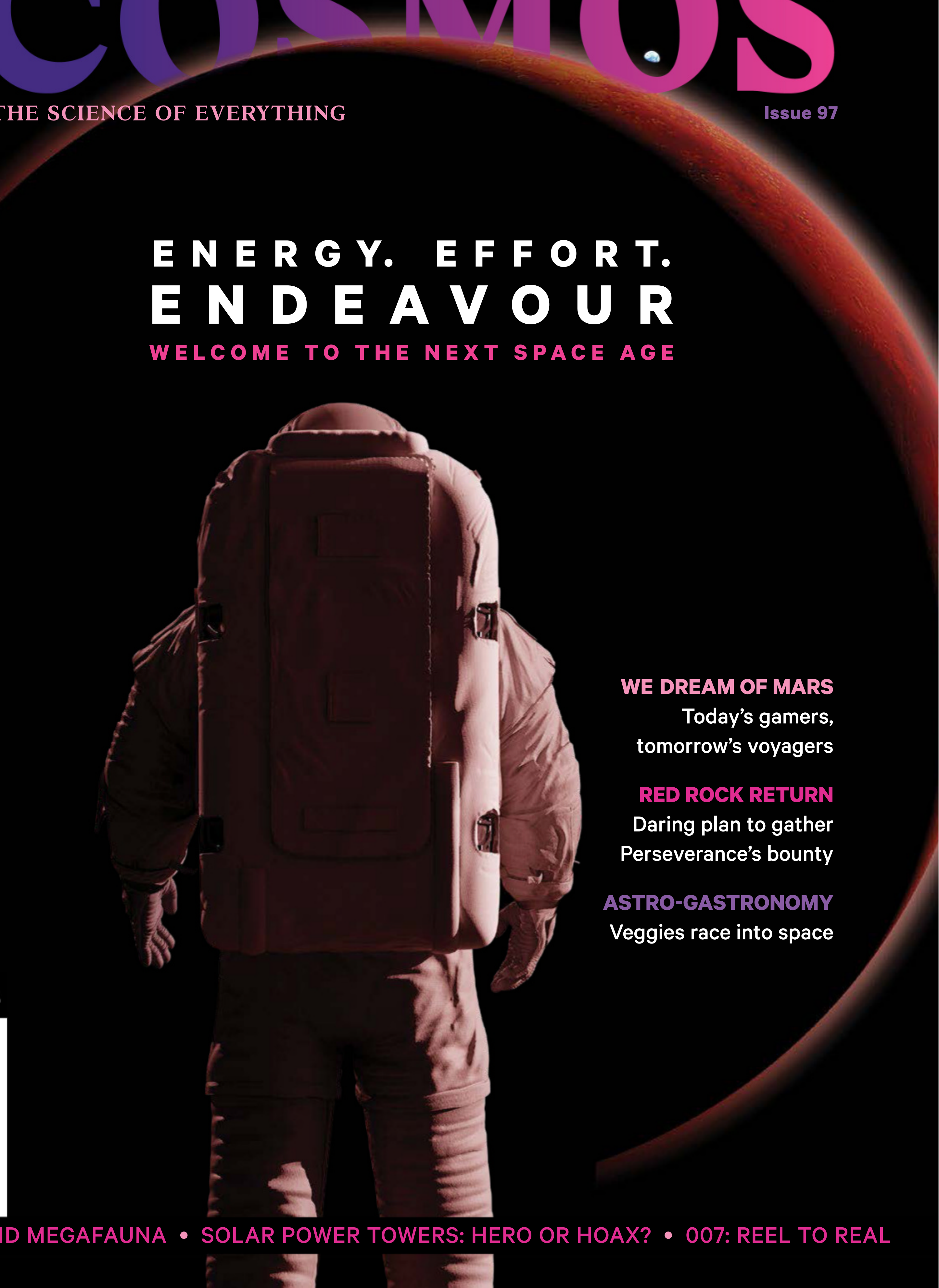
GLOW WITH THE FLOW DIVING INTO THE MARINE CREATURES THAT CREATE LIGHT

COSMOS

THE SCIENCE OF EVERYTHING

Issue 97



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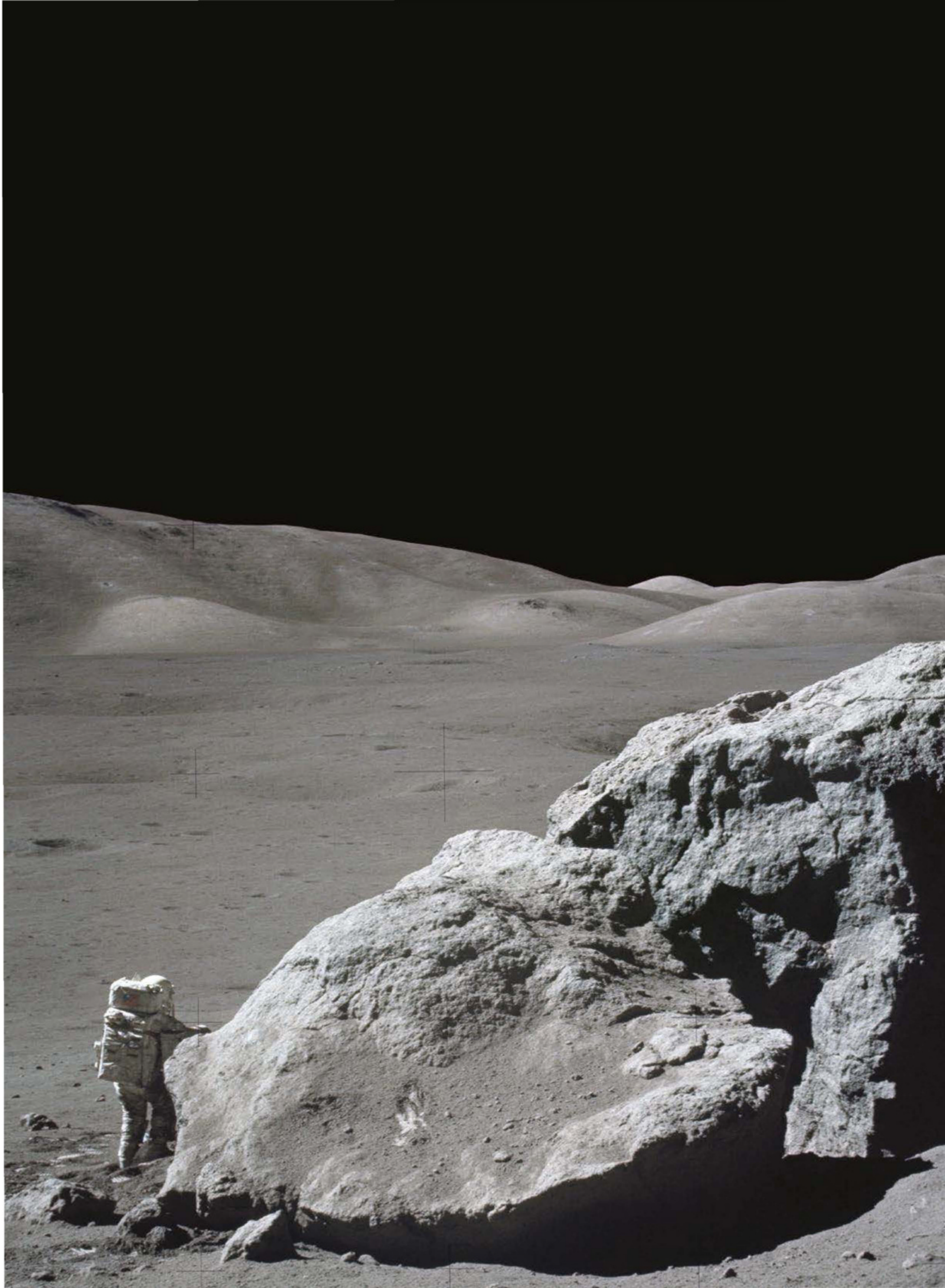
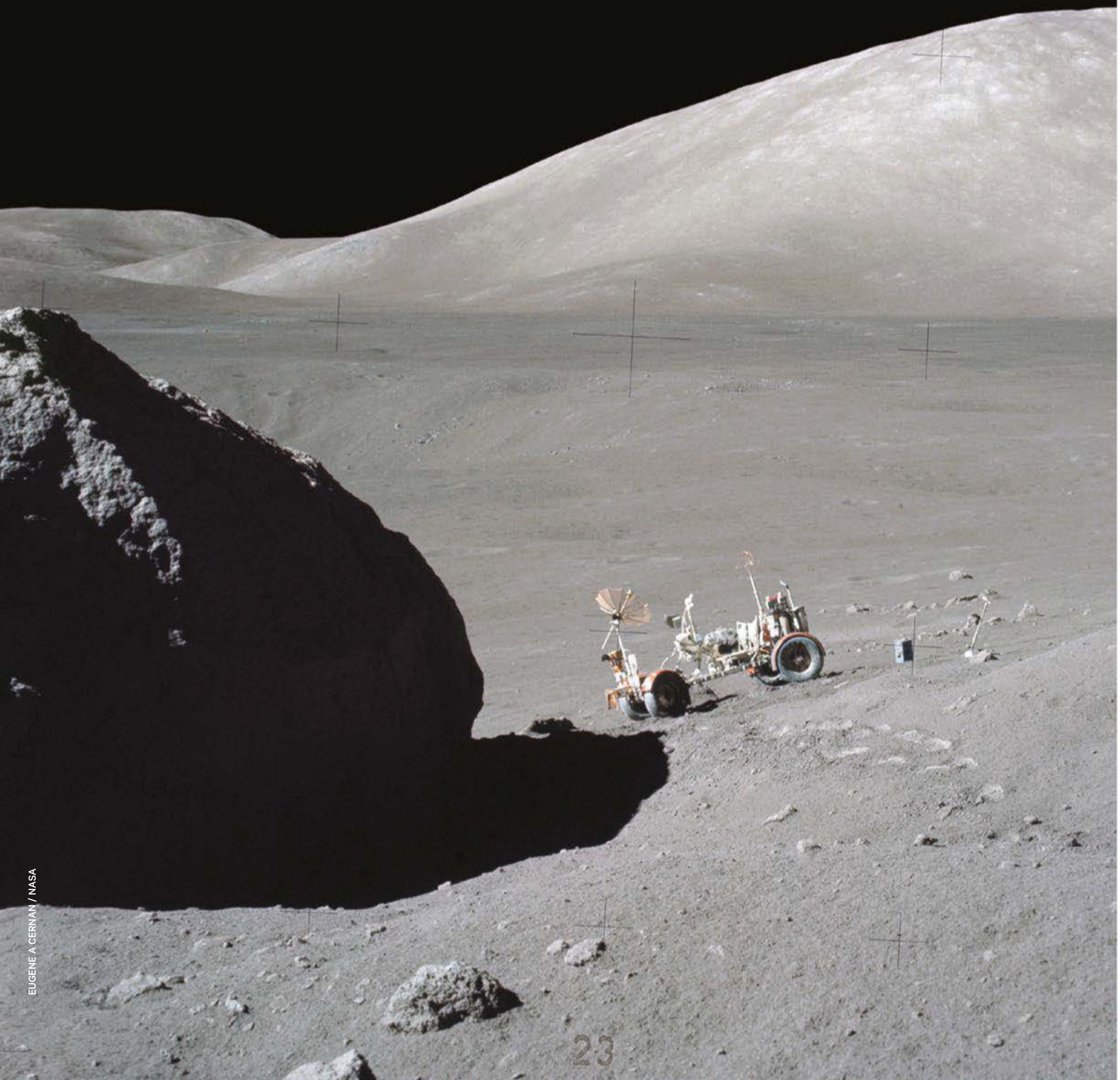


Explorers then – and again

There's great symmetry in the current Artemis mission, humankind's return to crewed deep space exploration, and the 50th anniversary of Apollo 17 – the most recent human Moon-landing mission. That journey saw Harvard PhD Harrison Schmitt, bottom left, become the only professional geologist to walk on the Moon. Mission commander Gene Cernan took this photograph, near the lunar module's Taurus-Littrow landing site, on 13 December 1973; the astronauts safely returned to Earth on 19 December. For space exploration in this issue, turn to page 40 to learn about planning for the Mars samples retrieval mission; to page 74, for a look at the critical business of growing food in space; and to page 86, to consider how mere video games might be the spark that ignites the next generation of human deep-space explorers.



EUGENE A CERNAN / NASA

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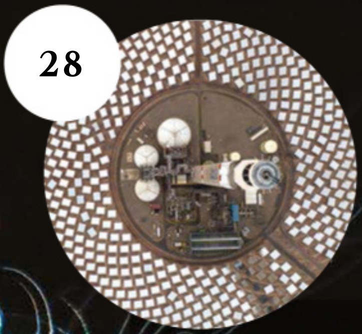

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Crystal jellies (*Aequorea victoria*) are a type of bioluminescent hydrozoan jellyfish, or hydromedusa, that is found off the west coast of North America.

GARY KAVANAGH / GETTY IMAGES

Next year?

The lights-off on one year always gets us thinking about the next. Here's what the *Cosmos* newsroom (along with our podcast host, Sophie Calabretto) is looking forward to in 2023.

Clare Kenyon
Imagine you could stick a pipe in the ground, whip out some hot water, extract the heat and then pump the water back underground. This isn't (just) a pipe dream: Australia has vast underground heated aquifers we could use.

Jacinta Bowler
I'm excited about Australia's next steps in space and quantum computing. Both of those are areas where we excel – and between satellite launches and silicon quantum computers we're on the cusp of something great. Also cool: satellites capable of tracking big emitters to hold them to account.

Sophie Calabretto
After what I learnt this year, I'm excited: they're teaching AI to make dubstep. And unlike self-driving cars, it's going to work. I'm also looking forward to eating gummy bears that were once wind turbine blades.

Ellen Phiddian
It'll be a good year for the sunniest parts of regional Australia: half a dozen big batteries, several huge solar farms and maybe even a hydrogen electrolyser factory are slated to open. And a total solar eclipse will be grazing Exmouth, WA.

Evrim Yazgin
SABRE South is a Victorian experiment searching for dark matter mirrored in the northern hemisphere. In 2023, SABRE will hopefully produce results confirming or denying the presence of dark matter, hypothesised to be five times more abundant than regular matter in the universe.

Matthew Agius
Several fascinating space exploration projects are set to hit their stride next year, like NASA's Psyche mission to explore a metal asteroid, Europe's dark matter telescope Euclid and Jupiter moon study JUICE, and potentially the first All-Australian orbital rocket Eris.

Imma Perfetto
I'm most excited about seeing how Bluetooth tagging and citizen science can be used together for tracking koala populations in my own backyard here in Adelaide. And, as always, I'm eagerly awaiting 2023's published research about the science of dogs – which never fails to amaze me.

Petra Stock
Looking for solutions to transport emissions beyond car- and tech-centric approaches. Research which lights the path towards more efficient, cleaner, healthier, friendlier cities by moving more people and goods via buses, trains, bikes and walking.

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From the Editors

“A LITTLE HARD WORK never hurt anyone.” A fine parental truism, and annoying to children in any era. Then along comes a problem – a war, climate catastrophe, pandemic. Suddenly people who work hard, who cleave to task, seem awfully useful. And what they create – the problems they solve – pave the way to a future that starts to feel a little less difficult, and a lot more exciting.

Rick Lovett kicks things off this issue with a look at the methods being calculated to bring substrate samples back from Mars (and we thought *getting* there seemed hard). It’s a daring plan, with each iteration containing rocketloads of problems to imagine a solution for. Also in space, Jamie Seidel takes a look at the veggies vying for a place there and explains why some university pond weed might be the height of astronaut gastronomy in our space-exploratory future.

Back on Earth, Tania Ewing reveals the inside story of an informal group of scientists whose timely pandemic thought experiment has transformed the way we think about clinical trials. Brett Mason shares the behind-the-scenes tale of two Australian scientists whose teams’ improvisational work created innovations that shaped World War II, helped end it and saved lives that might have been lost to it. Direct from the field, David Hancock reports on a collaboration combining Indigenous knowledge and modern tech to investigate marine mammals in the waters surrounding the remote Wessel Islands, in Yolngu Country, NT. And Rachel Williamson unpacks the tricky tech of centralised solar’s tower of power. So far, so problematic, but is there light at the end of the tunnel?

Happily, the issue’s not all hard yakka: there’s time too for a little relaxed reading. Ooh-aah moments come from biologist (and jellyfish goddess) Lisa-ann Gershwin, who leads a tour of marine bioluminescence; the cracking chemistry of eggs; real-life Bond gadgets; and surprising sunscreen science.

Now, 2023 beckons – and with it the cautious, hopeful feeling that reward for all that effort will lighten the days and months ahead. Thanks, science.

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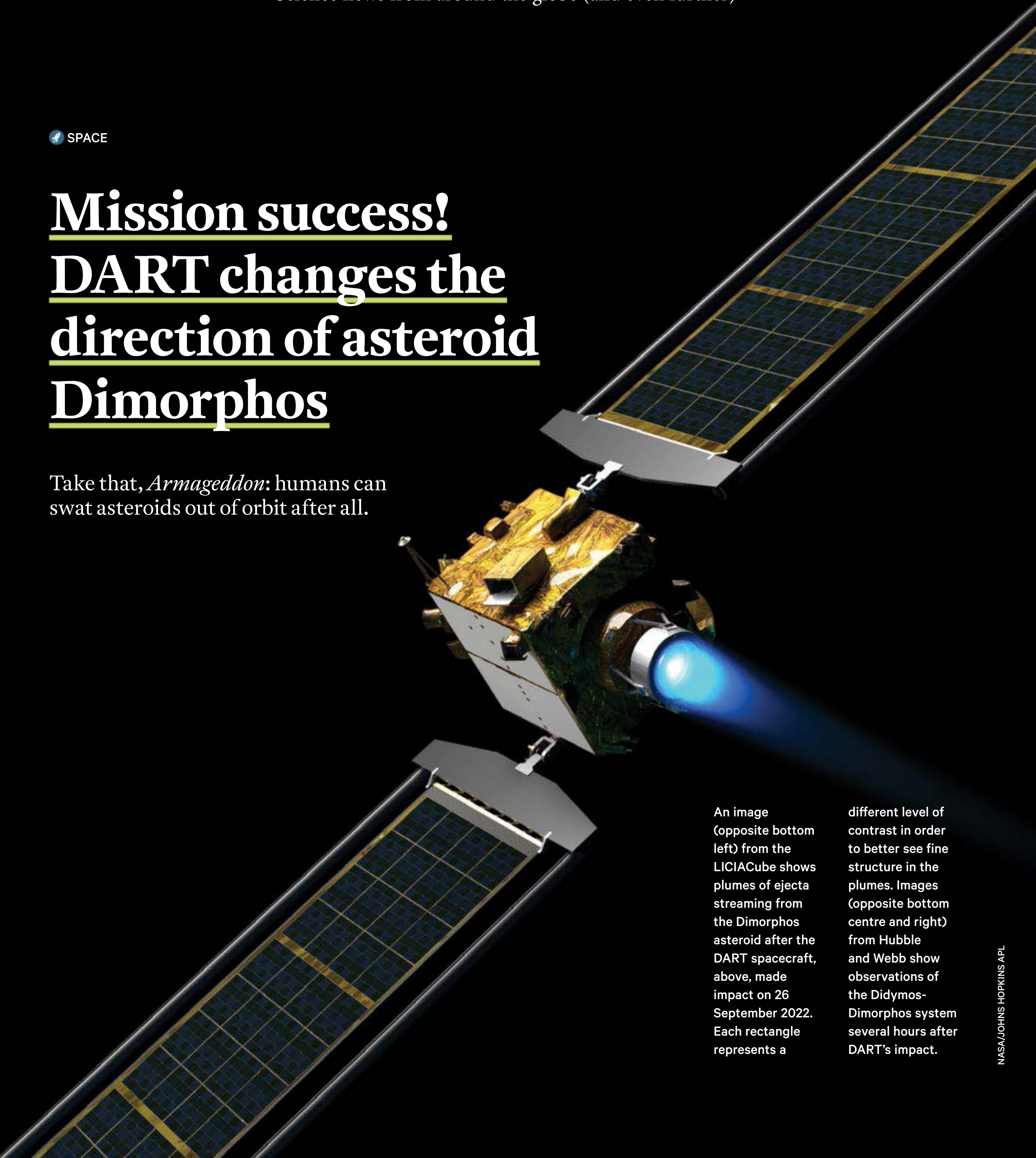
SPACE

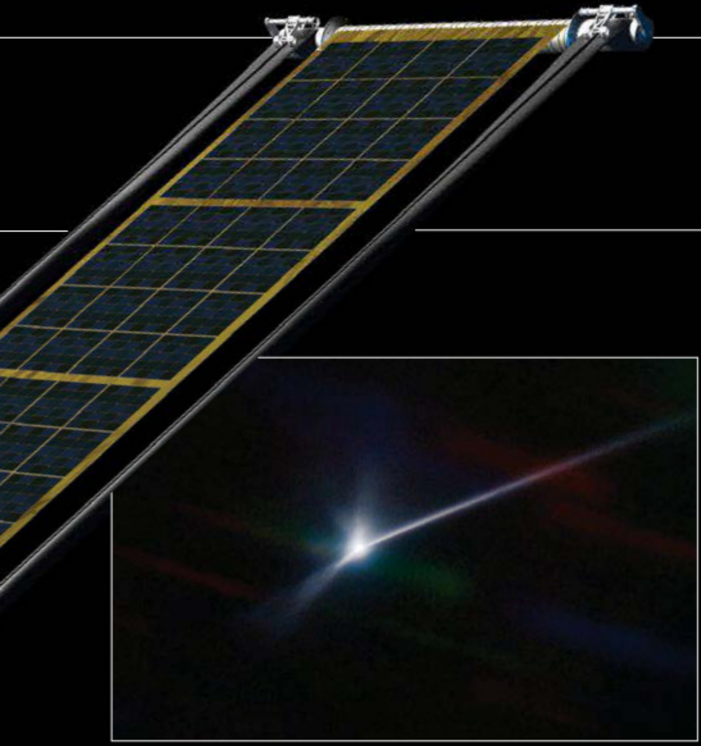
Mission success! DART changes the direction of asteroid Dimorphos

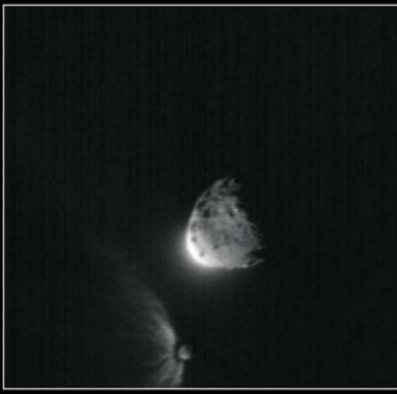
Take that, *Armageddon*: humans can swat asteroids out of orbit after all.



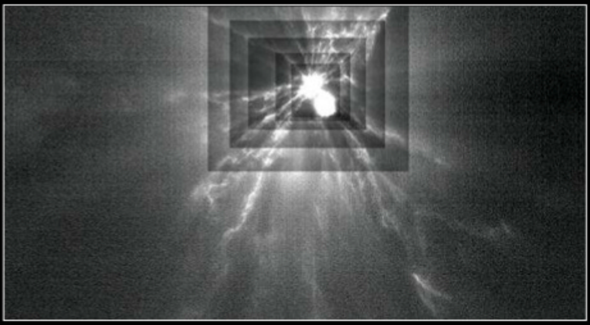
An image (opposite bottom left) from the LICIACube shows plumes of ejecta streaming from the Dimorphos asteroid after the DART spacecraft, above, made impact on 26 September 2022. Each rectangle represents a different level of contrast in order to better see fine structure in the plumes. Images (opposite bottom centre and right) from Hubble and Webb show observations of the Didymos-Dimorphos system several hours after DART's impact.

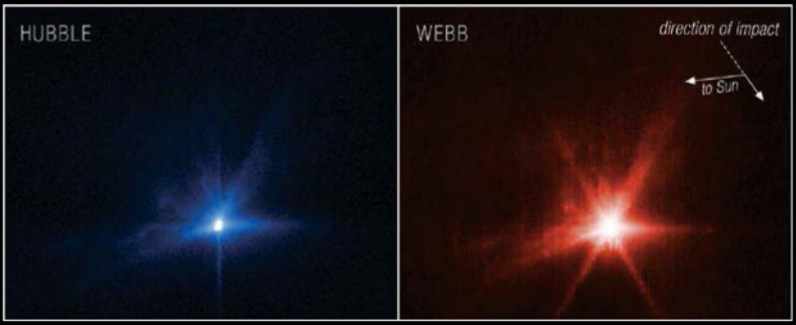
NASA/JOHNS HOPKINS APL





A vast plume of debris (far left) blasted from the surface of Dimorphos forms a more than 10,000km long dust trail. Pushed away by the Sun's radiation pressure – not unlike the tail of a comet – it stretches from the centre to the top right-hand edge of the field of view. The LICIACube satellite acquired this image (left) just after its closest approach to Dimorphos, after the DART impact.





CLOCKWISE FROM TOP LEFT: CTIO/NOIRLAB/SOAR/NSF/AURA/T KARETA (LOWELL OBSERVATORY), M KNIGHT (US NAVAL ACADEMY). ASI/NASA. NASA, ESA, CSA, JIAN-YANG LI, CRISTINA THOMAS, IAN WONG; IMAGE PROCESSING: JOSEPH DEPASQUALE, ALYSSA PAGAN. ASI/NASA/APL

The DART mission to change the path of an asteroid has successfully achieved its objective and moved a stadium-sized space rock further than NASA originally expected.

In September, the Double Asteroid Redirection Test (DART) spacecraft deliberately smashed into the surface of the asteroid Dimorphos at more than 23,000 km/h after an 11-million-kilometre journey.

It was part of a mission by NASA and the Applied Physics Laboratory at Johns Hopkins University to see whether human intervention could alter the trajectory of a space object.

NASA confirmed the orbit of the target asteroid was been changed by the high-speed impact, marking the successful completion of the project started back in 2017.

The US$330 million spacecraft's impact was only expected to shift the position of Dimorphos by one millimetre, but in the scheme of its 11-hour, 55-minute orbit around the nearby asteroid Didymos, even this miniscule shift could shave over a minute from its space loop.

Prior to the impact, the mission team finalised its calculations of Dimorphos' orbit by measuring the eclipses between the 160 metre asteroid around its 780m parent – each dip of light as one passes in front of the other providing calibration intervals for scientists on Earth.

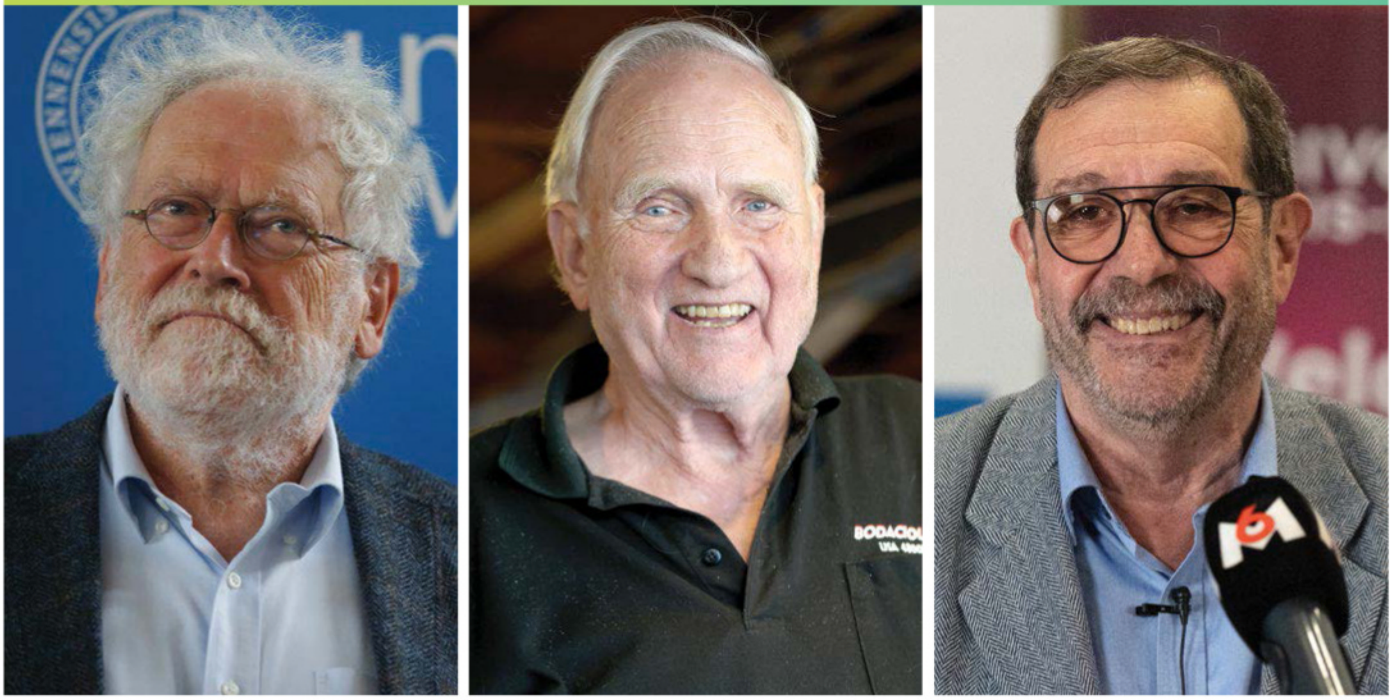
That process was repeated in the aftermath of the collision using telescopes at Lowell Observatory in Arizona and the Giant Magellan Telescope in Chile.

The calculations found a 32-minute change in Dimorphos' orbit time – 25 times greater than the mission's 73-second benchmark.

"This result is one important step toward understanding the full effect of DART's impact with its target asteroid," says NASA Planetary Science Division director Lori Glaze.

Understanding the unique properties of Dimorphos will inform future planetary defence planning by NASA. These analyses will be assisted by the LICIACube satellite currently in the vicinity of the impacted asteroid, as well as the European Space Agency's upcoming Hera mission.

Nobel Prizes 2022



▲ Nobel Physics laureates 2022 (left to right): Anton Zeilinger, John Clauser and Alain Aspect.

HEINZ-PETER BADER/STRINGER/GETTY IMAGES NEWS. JUSTIN SULLIVAN/STAFF/GETTY IMAGES NEWS. SAM TARLING/STRINGER/GETTY IMAGES NEWS.

PHYSICS

Entangled photons and quantum

Physicists opened doors to another world.

Physics gets weird in the tiny world of atoms and particles. This year's Physics Nobel laureates – Alain Aspect, John Clauser and Anton Zeilinger –have explored quantum entanglement in photons to open up a whole array of potential applications of entanglement.

For example, developments in quantum computing are set to revolutionise the way in which we are able to process information.

Quantum entanglement – referred to by Einstein as "spooky action at a distance" – is a bizarre effect where the states of two "entangled" particles are linked no matter how far apart they get.

But neither particle exists solely in a single state. Each particle's position, momentum, and other physical observables are undetermined until measured. That is, they live in what's called a "superposition" of states all at once. Only once measured does the particle "collapse" into a single state – which state the particle collapses into is determined by the probability of the particle being in that state.

In 1997, Zeilinger's team created an entangled pair of particles, A and B. Shooting the pair in opposite directions, particle A meets a third particle, C. Entangling with the new particle, A and C are in a new shared state. While particle C has lost its uniqueness, its identifying properties are transferred to particle B through its entanglement with particle A.

This mind-boggling effect is called quantum transportation and is incompatible with a "hidden variable" approach.

The prize was awarded "for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science", highlighting the importance of verifying this theoretical work experimentally in the development of new technologies.

Quantum information science is a "vibrant and rapidly developing field," says Eva Olsson, a member of the Nobel Committee for Physics. "Its predictions have opened doors to another world, and it has also shaken the very foundation of how we interpret measurements."

MEDICINE

DENISOVAN DNA

Scientist rewrote the book on Neanderthal genome.

The 2022 Nobel Prize in Physiology or Medicine has been awarded to Svante Pääbo, whose team published the first Neanderthal genome sequence and has since pioneered genomic analysis into both Neanderthals and the mysterious Denisovans.

The researcher has been awarded the prize "for his discoveries concerning the genomes of extinct hominins and human evolution" and his research gave rise to a new discipline – paleogenomics.

DNA degrades over time, so extracting even limited information is difficult. In 1997, Pääbo made his first breakthrough by reconstructing the mitochondrial DNA from a Neanderthal. In 2010 came a second major result, with the publication of the first draft of the Neanderthal nuclear genome sequence.

"Pääbo's discoveries have had a profound impact on the understanding of our evolutionary history, and they have galvanized research in the area," wrote Gunilla Karlsson Hedestam and Anna Wedell, professors at the Karolinska Institute.

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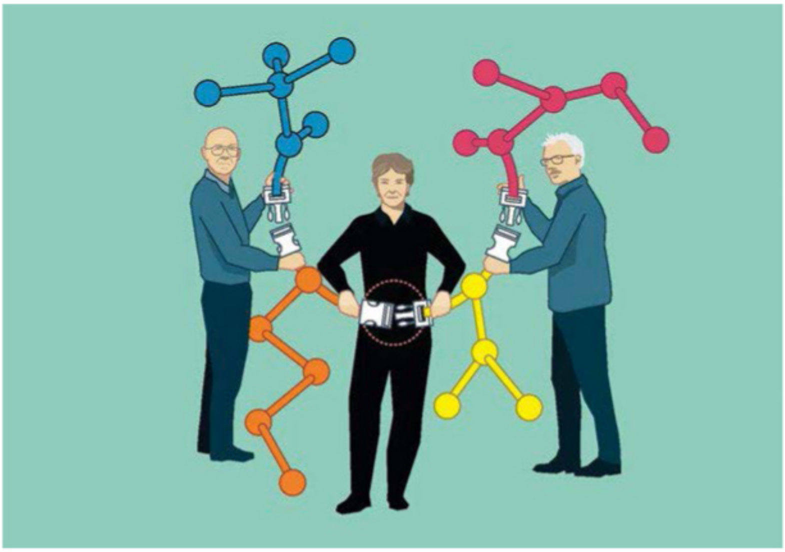
CHEMISTRY

How click chemistry changed the world

Chemists win prize for sharpening and slimming some of our best tools.



Using the tens of thousands of reactions discovered over the last century, it's possible for a chemist to make just about any molecule imaginable.

But if you're trying to make lots of something, like a pharmaceutical, you need to be able to do it cheaply, precisely, and with as few dangerous ingredients as possible.

That's much harder, and the solution has won Carolyn Bertozzi, Morten Meldal and Barry Sharpless the 2022 Nobel Prize for Chemistry "for the development of click chemistry and bioorthogonal chemistry".

Sharpless has been lauded for refining a list of chemical reactions that met these requirements.

Named "click chemistry", this list has become a first point of call for many, many chemists. Among the clicks, there was one reaction that drew the most interest: called 1,3-dipolar cycloaddition, it was super fast and efficient, but initially lacked precision.

So Sharpless and Meldal independently developed a copper catalyst that, like a pair of hands fastening a seatbelt, completed this reaction neatly and effectively. The copper click revolutionised a lot of chemical synthesis.

Bertozzi then figured out a way to do this reaction without copper: meaning it could be used in biological applications.

This led to "bioorthoganal" chemistry, or reactions that happen on a cell's surface without disrupting its behaviour. It's been critical to the development of several cancer pharmaceuticals now in clinical trials.

Read more about the Nobel 2022 prizewinners at cosmosmagazine.com

ANTHROPOLOGY

Evidence discovered that human evolution was driven by major environmental pressures

Study finds selection pressures likely caused some favourable genes to increase within human groups.

The genes of ancient humans might have changed substantially due to environmental pressures and change, say an international team of researchers.

A widely held belief related to human evolution is that our ancient ancestors' ability to fashion tools, shelter, and use advanced communication skills may have helped to shield them from large environmental impacts such as changing climate, disease and exposure to other events affecting mortality.

But research led out of the University of Adelaide suggests that beneficial genes may have played a more important role in preserving our ancestors.

Until now, the sudden increase in frequency of these genes in human groups was masked by the exchange of DNA between people during reproduction.

Now, analyses of more than 1000 ancient genomes dating as far back as 45,000 years ago have found historic signals showing that genetic adaptation was more common than previously thought.

"Evolutionary events [are] exactly what shape our genetic diversity today," says co-lead author Dr Yassine Souilmi.

"That's what makes us vulnerable to certain diseases [and] resistant to others. Having a good understanding of evolution, we can have a better understanding of who we are."

Previous University of Adelaide research has uncovered a range of evolutionary trends, from historic climate change causing the demise of ancestral lions and bears, to the first interactions between humans and coronaviruses 20,000 years ago.

And the broader field of research into ancient DNA has shed light on important moments in human history. Only recently did analyses of ancient genes uncover locations on the human genome associated with surviving *Yersinia pestis* – the bacterium that causes the bubonic plague.

The study, in *Nature Ecology and Evolution*, has similarly found environmental events might have been more influential on evolution among Eurasian groups.

Such events might lead to a point of natural selection. Take, for instance, the emergence of a pathogen. If such a disease could kill people, those who managed to survive and continue reproducing would pass down favourable traits to subsequent generations.

"Natural selection acts in two different mechanisms," says Souilmi. "It only cares about whether you're procreating successfully... when it acts, it's either killing a lot of people, [preventing] some people from reproducing successfully, or some people are just not finding mates because they have some sort of ailment that's not allowing them to mate successfully, or might make them undesirable.

"What we're finding is that the signal of natural selection we detected in this [research] was likely a single event, because the signal is clustered in time in a very early migration out of Africa.

"Not all of the [events] we detected occurred at the same time, but the bulk of them did."

▲ It's all in the genes. Researchers believe it's more likely that environmental pressures influenced genetics than that human ingenuity shielded our ancestors from those pressures.

MIKE BAXTER

CLIMATE

METAL TURNS VEXATIOUS PLASTIC INTO A SUSTAINABLE FEEDSTOCK

Chemists are taking on the irritating chemistry of polyethylene.

Polyethylene is one of the most common types of plastic in the world. Easy to make, it's devilishly difficult to break down again, making re-use and recycling tricky.

In *Science*, US chemists showed they've figured out a new way to return polyethylene into component parts – a discovery which could one day make it fully circular.

Polyethylene is made from carbon atoms connected to each other in a chain, with hydrogen atoms branching off. The bond between carbon atoms is difficult to break, and even tricker to break in a systematic way.

The researchers' innovation was to use a couple of different metals. The first relies on a catalyst made from iridium, or platinum and zinc, to modify the hardy carbon-carbon bond.

Then, a palladium-based catalyst could pounce on that bond and use it to progressively break up the polymer with a substance called ethylene.

BIOLOGY

Dogs might smell when we're stressed

Dogs differentiate breath and sweat samples from people before and after a stress-inducing task.

We know dogs can recognise human emotions based on audio and visual clues, but could they also be using their sense of smell to get an idea of our state of mind?

Researchers found that dogs could accurately detect the breath and sweat samples from stressed participants 93.75% of the time.

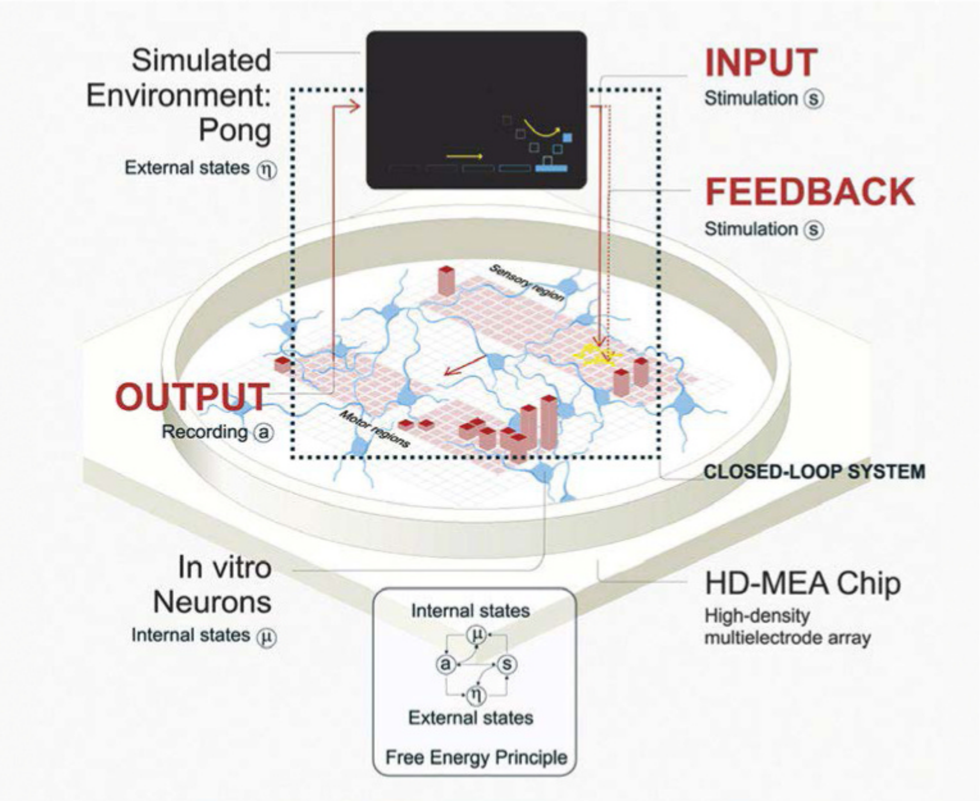
The results, published in *PLoS ONE*, could have applications in training Emotional Support and Post Traumatic Stress Disorder service dogs.

Researchers collected samples of breath and sweat from non-smokers who had not recently eaten or drunk. Samples were taken before and after completing a stressful task – a fast-paced arithmetic test – alongside self-reported stress levels and heart rate and blood pressure measurements.

"The findings show that we, as humans, produce different smells through our sweat and breath when we are stressed and dogs can tell this apart from our smell when relaxed – even if it is someone they do not know," says co-author Clara Wilson, from the School of Psychology at Queen's University Belfast, in Northern Ireland. "The research highlights that dogs do not need visual or audio cues to pick up on human stress. This is the first study of its kind and it provides evidence that dogs can smell stress from breath and sweat alone, which could be useful when training service dogs and therapy dogs."

KERRY CAMPBELL, CC-BY 4.0 – 850, ANJA IVANOVA/GETTY IMAGES

BIOLOGY



A graphical representation of DishBrain playing Pong.

KAGAN ET AL., NEURON, 2022.

If 'DishBrain' can learn to play Pong, what does it mean for science?

Brains-on-a-chip have existed for years, but this is the first time cells have been stimulated and measured for a response.

It sounds like the start of a nerdy joke: What can you do with 800,000 brain cells, a computer chip and Pong? If you're an Australian commercial startup, the answer is apparently "create sentience".

It's a pretty big claim, but the team's system – called DishBrain – does seemingly learn how to play a version of the game Pong, which gives us a perfect chance to understand what a "brain-on-a-chip" even is.

"The beautiful and pioneering aspect of this work rests on equipping the neurons with sensations – the feedback – and crucially the ability to act on their world," says one of the authors, Professor Karl Friston, a theoretical neuroscientist at University College London.

"Remarkably, the cultures learnt how to make their world more predictable by acting upon it. This is remarkable because you cannot teach this kind of self-organisation; simply because – unlike a pet – these mini-brains have no sense of reward and punishment," he says.

To be clear, this isn't a brain. The human brain has somewhere in the region of 86 billion neurons. A mouse has 70 million. DishBrain has a similar number of neurons to a bumblebee.

But even if DishBrain *did* have 86 billion neurons, we just don't know enough about the human brain to be able to create anything resembling a human brain.

Let's again consider – DishBrain just learnt how to play Pong, so it's probably worth understanding how it works.

The team placed either hiPSC human neurons or E15 mouse embryo neurons onto a high-density multi-electrode array – think of this like a silicon chip in a medium-filled petri dish.

The neurons were set up to play Pong by inducing zaps of different voltages depending on where the ball was in relation to the paddle. Electrodes on the left or right of one array were fired to tell DishBrain which side the ball was on, while distance from the paddle was indicated by the frequency of signals. There was a higher voltage at random locations if DishBrain didn't hit the ball back.

This created a system where the cells started to "learn" how to play better over time. It's not going to be beating a human any time soon – it hit only slightly more than it missed. But it *was* better than a system that had received stimulus but no feedback.

"I think if you saw a bumblebee manage to play the game of Pong and it could hit more often than it misses, I think you'd be fairly impressed with the bumblebee," says lead author Brett Kagan, chief scientific officer at Cortical Labs.

"I think that's the right sort of approach in considering its performance here."

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FOCUS: AVIAN RESEARCH

01

Woodpecker drumming uses the same regions of the brain as vocal learning and production in songbirds.

02

Conservationists to track released critically endangered plains-wanderers (shown here) using tiny, solar-powered, satellite backpacks.

03

Dr Dominique Potvin, behavioural ecologist and senior lecturer in animal ecology, explains current ideas about the reasons for the dawn chorus.

04

Cell study shows Nestling pied flycatchers react to songs from their own dialect, compared to the songs of another species and even different populations in their own species.

05

AAD research shows massive reduction in the numbers of breeding Adélie penguins in some – but not all –places in Antarctica.

06

German research finds birds might have a more efficient way of processing glucose, meaning that bird neurons need about a third less than neurons in a mammalian brain.

07

CSIRO study finds birds at Australian study sites died at a rate three times greater during a very hot summer compared to a mild summer.

www.cosmosmagazine.com/ **01** science/drumming-woodpecker-same-as-singing/ **02** nature/plains-wanderer-solar-satellite/ **03** nature/birdsong-dr-dominique-potvin/ **04** nature/baby-songbirds-recognise-local-dialect/ **05** news/whats-going-on-with-adelie-penguins/ **06** science/bird-brain-might-not-be-a-good-insult/ **07** nature/massive-number-of-bird-deaths-heatwaves/

ALEX PIKE / *PEDIONOMUS TORQUATUS*

CLIMATE

Big three greenhouse gases hit record highs

Largest year-on-year jump in methane concentrations since measurements began nearly 40 years ago.

In a stark update on the current state of global climate change, a report by the World Meteorological Organisation (WMO) has found that atmospheric levels of the three main greenhouse gasses reached record highs in 2021.

Global average carbon dioxide concentrations were 415.7 parts per million (ppm), methane 1908 parts per billion (ppb) and nitrous oxide 334.5 ppb.

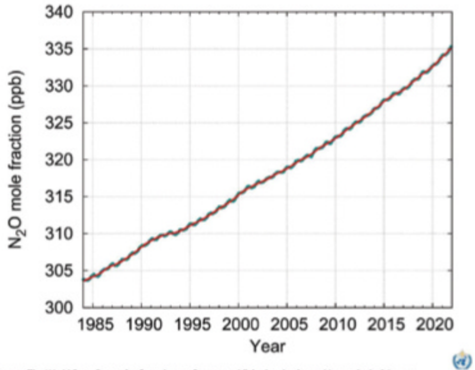
The WMO report says researchers detected the largest year-on-year jump in methane concentrations since systematic measurements began nearly 40 years ago. The increase in average carbon dioxide levels between 2020 and 2021 (2.5 ppm) was greater than the annual growth rate over the past decade (2.46 ppm/year).

The causes behind these exceptional increases in greenhouse gases are still being investigated.

"WMO's Greenhouse Gas Bulletin has underlined, once again, the enormous challenge – and the vital necessity – of urgent action to cut greenhouse gas emissions and prevent global temperatures rising even further in the future," said WMO Secretary-General Professor Petteri Taalas.

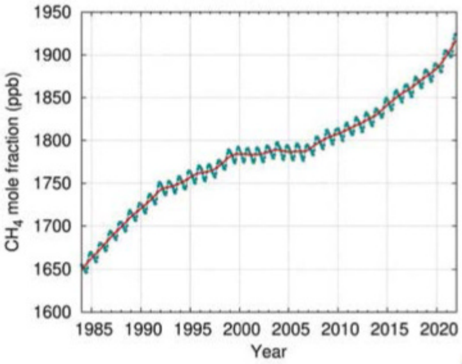
"The continuing rise in concentrations of the main heat-trapping gases, including the record acceleration in methane levels, shows that we are heading in the wrong direction," he said.

Nitrous Oxide



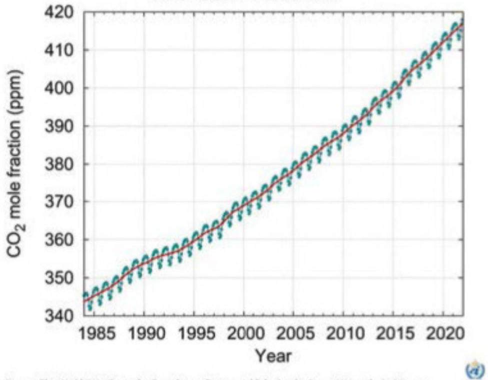
Source: The World Data Centre for Greenhouse Gases established at the Japan Meteorological Agency

Methane



Source: The World Data Centre for Greenhouse Gases established at the Japan Meteorological Agency

Carbon Dioxide



Source: The World Data Centre for Greenhouse Gases established at the Japan Meteorological Agency

KANO LAB/KYUSHU UNIVERS. WMO

NATURE

CAPTURING THE MAJESTY OF NATURE IN 3D

A publicly accessible encyclopedia of digital animal and plant models.

A digital encyclopedia is capturing animal and plants in 3D. The publicly accessible database, which contains 1,400 detailed 3D models to date, is the creation of Yuichi Kano from Kyushu University, Japan.

As detailed in *Research Ideas and Outcomes*, Kano produces each 3D model using a technique called "bio-photogrammetry" to create the 3D digital models.

Photogrammetry is used to scan everything from landscapes to sculptures.

To make each model, Kano suspends each organism from a fishing line, photographing the sample hundreds of times from multiple angles.

The best 500 images are then loaded into a photogrammetry program, which creates the digital model.

"It is similar to how the 'bullet time' sequences were filmed in the first *Matrix* movie, except instead of Keanu Reeves on a line surrounded by cameras, we use an octopus," Kano says.

GEOLOGY

Supercomputer model predicts supercontinent to form in Pacific

Earth's continents collide every 600 million years.

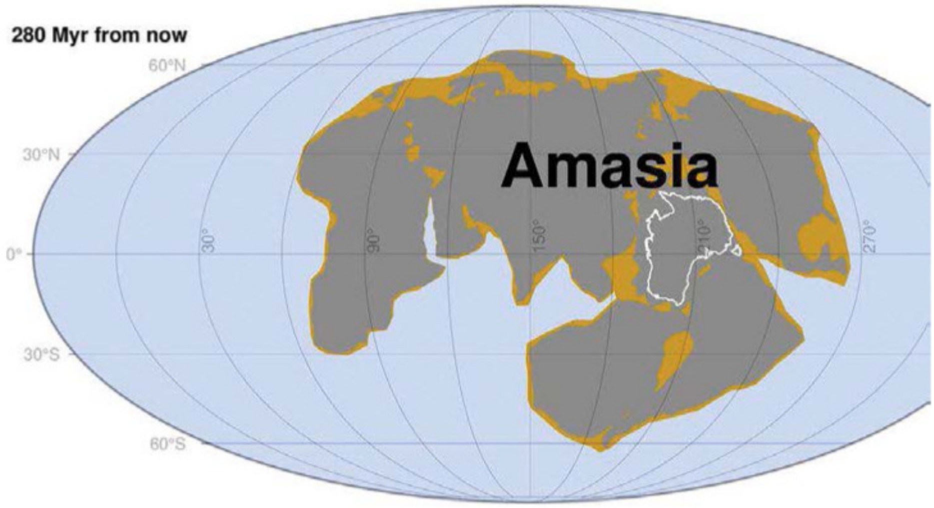
The world's next supercontinent will form when the Pacific Ocean closes in 200–300 million years, according to new research in *National Science Review*.

Earth's continents move very slowly over the mantle. The Australasian plate is one of the faster moving ones, creeping northward at around seven centimetres per year.

Using a supercomputer, geologists were able to simulate the formation of supercontinents. Their results show that the cooling of Earth over billions of years causes the thickness and strength of the plates under the oceans to reduce. So, "younger" oceans like the Atlantic and Indian are more resistant to continental drift than the more worn-down Pacific.

"Over the past two billion years, Earth's continents have collided to form a supercontinent every 600 million years," says Dr Chuan Huang, from Curtin University's Earth Dynamics Research Group. "This means that the current continents are due to come together again in a couple of hundred of million years' time."

The future landmass has been dubbed Amasia. "Australia is also expected to play a role in this important Earth event, first colliding with Asia and then connecting America and Asia," says Huang.



EARTH

EXTINCT ANIMAL WAS JUST HIDING UNDER A ROCK

Scientists find long-lost insect after an 80-year absence.

When Maxim Adams turned over a rock on Lord Howe Island's northern coastline, he wasn't expecting to find a long-missing animal.

"I lifted the first rock under this huge banyan tree, and there it was. For the first 10 seconds or so, I thought 'No, it can't be'," Adams says.

'It' is *Panesthia lata* – the Lord Howe Island wood-eating cockroach – a species thought to have been wiped out by the arrival of rats on the island in the 1910s.

Adams and his supervising professor Nathan Lo spent a week searching for more colonies of the previously vanished arthropods, but to no avail.

Although Lo has written of the perseverance of cockroaches on neighbouring islands, *P. lata* is genetically distinct. "These cockroaches are almost like our very own version of Darwin's finches, separated on little islands over thousands or millions of years developing their own unique genetics," says chair of the Lord Howe Island board, Atticus Fleming.

LEFT: CURTIN UNIVERSITY. ©ESA/DLR/FU BERLIN, CC BY-SA 3.0 IGO, HTTPS://WWW.ESA.INT/ESA_MULTIMEDIA/TERMS_AND_CONDITIONS. ABOVE: JUSTIN GILLIGAN DPE.

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Researcher Hoshimoto's illustration of the new reaction. The lion – boranes and 2-methylquinoline – finds and holds the hydrogen molecules.

CHEMISTRY

A neat way to store and purify hydrogen

It's not emissions-free, but it's a smart way to keep it.

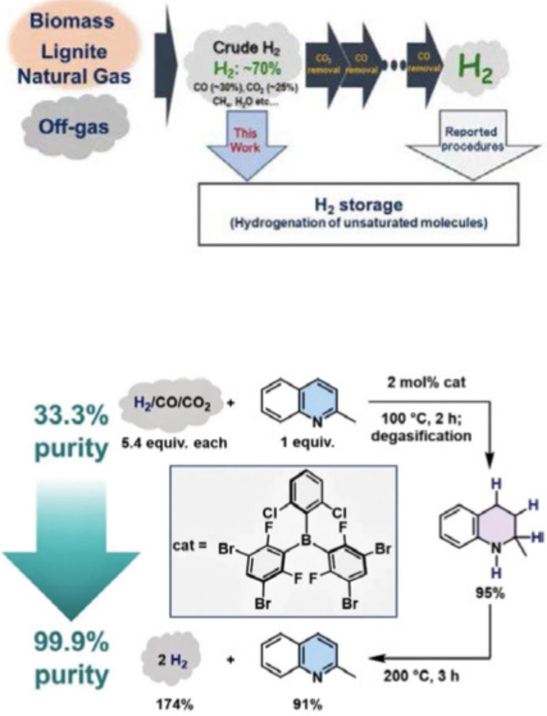
Hydrogen gas is going to be an increasingly important substance over the next decade, as a means of storing and transporting renewable energy.

But hydrogen *itself* is hard to store and transport: as a flammable, invisible gas, it can make for dangerous cargo, and the most common method of making it at the moment produces a lot of greenhouse gas emissions.

Research in *Science Advances* might have landed on both an easier way to store it, and a cheaper and less carbon-intensive way to make it. The researchers, at Osaka University in Japan, have found some substances that react with hydrogen, and only hydrogen – so they can store and release the gas with ease.

Currently, most commercial hydrogen is made from steam-reforming natural (methane) gas, producing carbon dioxide and other greenhouse gases in the process.

ENERGY STORAGE: A NEW APPROACH



The hydrogen made by this method is only about 70% pure: it also contains carbon monoxide, carbon dioxide, and trace amounts of other gases, each of which have to be removed individually through laborious, energy-intensive ways.

"Even a small amount of carbon monoxide can hinder hydrogen uptake," says corresponding author Associate Professor Yoichi Hoshimoto, from Osaka University's Department of Applied Chemistry.

"Thus, costly purification methods to isolate the hydrogen prior to storage are necessary."

The Osaka research has found that boron-based compounds called triaryl boranes could catalyse a reaction between hydrogen and another substance called 2-methylquinoline, causing the hydrogen to stick to the 2-methylquinoline. When heated at 200°C for three hours, the 2-methylquinoline released the hydrogen again. This method is a 99% efficient way to store hydrogen, and releases it at 99.9% purity.

The method still produces some carbon emissions in its first stage – unlike electrolysis, which can be a near zero-emissions way of making hydrogen. But this chemical trick could help boost the industry in its nascency, and provide a clever storage method.

"The industrial value of molecular hydrogen has long been plagued by substantial quantities of carbon monoxide and other contaminants," says Hoshimoto.

"However, in the catalytic hydrogenation method we developed, even a five-fold excess of a contaminant wasn't a problem, and hydrogen uptake and release were each achieved without using any solvents."

To cap it all, boron has gas storage potential – a few months ago, Australian researchers showed it could store and separate carbon-based gases too.

Y. HOSHIMOTO

NATURE

ALL ABUZZ: HOW BEES AND OTHER SWARMING INSECTS MAKE POWER

Insect swarms can produce as much electric charge in the atmosphere as a thunderstorm cloud.

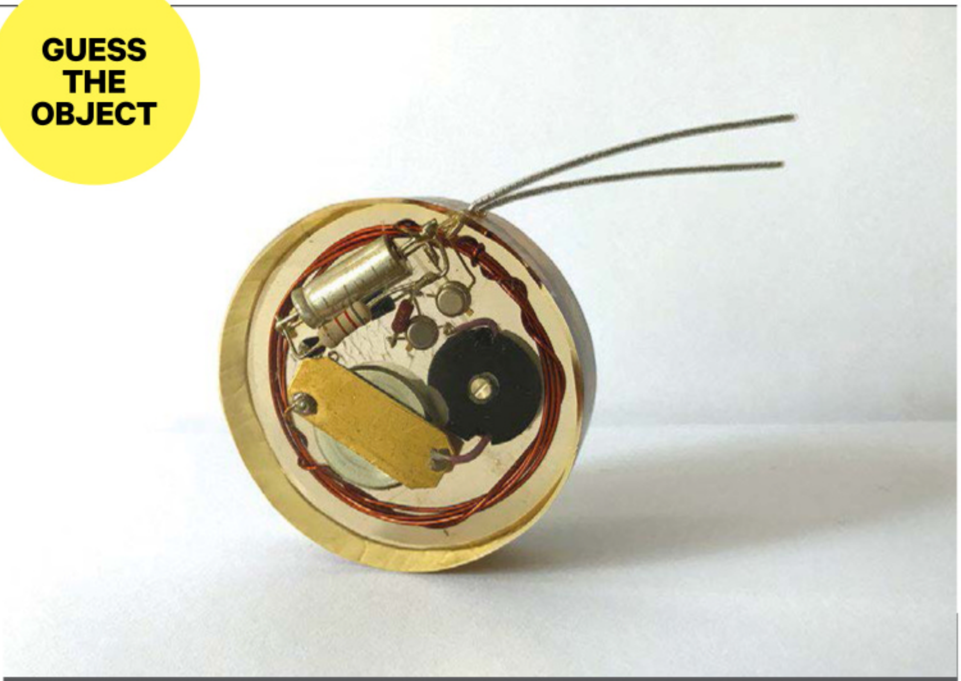
Biologists have made an electrifying discovery: swarming insects can impact the planet's electrical charge.

In trying to understand the way electric charge in the atmosphere changes due to many known factors (such as rain, aerosols, radioactivity, pollution and volcanism), researchers realised that the contribution from insects was an important, yet little understood, part of the puzzle.

The discovery, published in *Cell*, is an important reminder of the interconnectedness of different scientific disciplines, explains co-author Giles Harrison, an atmospheric physicist from the University of Reading. "Interdisciplinarity is valuable here – electric charge can seem like it lives solely in physics, but it is important to know how aware the whole natural world is of electricity in the atmosphere."

ABOVE: ELLARD HUNTING. TOP RIGHT: AGENT GALLERY CHICAGO. RIGHT: PHOTOQUEST / GETTY IMAGES

GUESS THE OBJECT

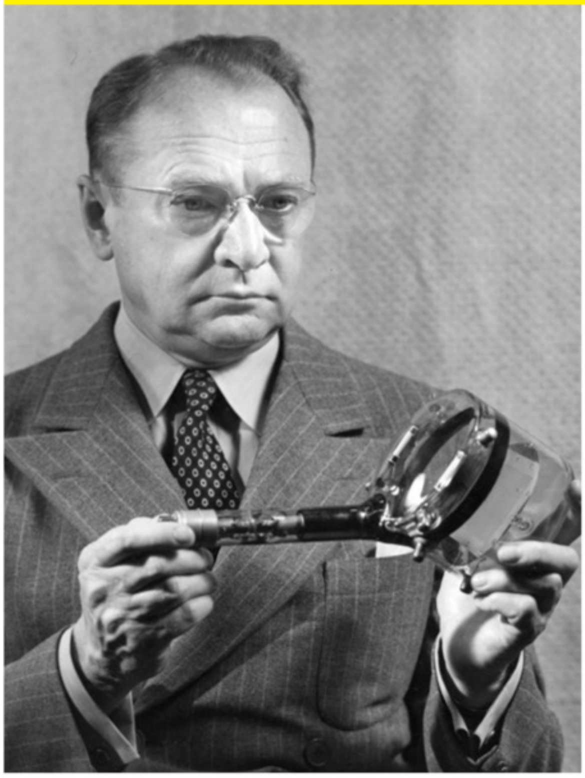


SMALL AND MIGHTY

The early thinking that led to this object dates back to the 19th century, but it was the 1950s before ideas translated into the engineered devices that have evolved and continue to be widely used today. This model is early generation – it dates to 1958 – and is of particular note. It attaches to a story of bravery, persistence and resilience. We're guessing that quite a few of you may recognise this fairly quickly, so we'll go easy on the clues. At a conference in 1983, one of its inventors said: "I must admit that at first I viewed [the device] more or less as a technical curiosity. So it was fantastic to see its tremendous development."

We know you can Google, but where's the fun in that? Tell us what you think it is. The correct answer – and/or the most creative – will be published in our next issue.

Send your hunches to contribute@cosmosmagazine.com



Last issue's object is an iconoscope – the first effective video camera tube to be used in early television cameras. The iconoscope out-performed earlier mechanical designs; it was the first fully electronic system. Vladimir K Zworykin, pictured here, filed two patents for a television system in 1923 and 1925 that described some of the iconoscope's operating principles. First correct responder on this one was Ray Martin: "The iconic invention is the iconoscope." Nailed it in six words. Humour featured in several entries (keep it up!). Mathew Faulkner's was a particular favourite: "It's Dr A M Phetamine holding the first ever vacuum-tube crack pipe." Special mention to Sue McAinsh – that's one wicked sense of humour, Sue.

MEDICINE

Scientists create a flatworm-inspired medical adhesive

Eeew.

▲ Flatworms, such as this Pseudoceros sp., are notoriously hard to identify and study due to their soft-bodied structure which lacks specialised circulatory and respiratory organs.

Uncontrolled haemorrhage – or loss of huge amounts of blood – might mean someone only has minutes between life and death.

In some situations, the wound can be compressed to stop the flow of blood, but some areas, such as the torso for example, can't be compressed.

Luckily "flatworm goop" is here to help, with researchers designing a bioadhesive inspired by flatworms' and mussels' ability to stick to some, frankly, gross surfaces. They've called it liquid-infused microstructured bioadhesives, or LIMB.

Some marine organisms adhere to bio-fouled surfaces with adhesives that feature microstructural architecture and infused liquid, the team write in a paper published in *Nature Communications*.

The researchers used pigs and rats to see how LIMB functioned. After cutting into a rat's or pig's liver, the team then measured how much blood was lost with gauze, combat gauze, a current medical device called SURGIFOAM and existing non-structured bioadhesives. LIMB did better than every other technology tested.

"Our material showed much-better-improved safety and bleeding-control efficiency than other commercial products," says McGill University bioengineer Professor Jianyu Li. "Beyond bleeding control, our material could one day replace wound sutures or deliver drugs to provide therapeutic effects."

DISCOVERY

REALLY GOOD VIOLINS MAKE HIDDEN, SUBTLE SOUNDS

Researchers home in on the acoustics of fiddles.

What makes a good violin sound so good? According to research in *The Journal of the Acoustical Society of America*, part of the reason is very subtle extra notes.

When two musical notes are played, listeners can sometimes hear "combination tones": an additional, subjective note that comes from the way the cochlea processes the two soundwaves in the inner ear. Some musical instruments can make these notes themselves: "objective combination tones". These notes are produced in the instrument, rather than the ear.

"Up to now, the combination tones generated by the violin were considered too small to be heard, and therefore, of no importance in music," says study co-author Giovanni Cecchi, of the Università di Firenze, Italy.

The researchers got a professional violinist to stand in the centre of an auditorium and play a series of dyads – two notes played simultaneously – on five different violins, all of different ages and qualities.

"We found that combination tones were much stronger and clearly audible in good violins," says Cecchi.

ART-DESIGN-PHOTOGRAPHY.COM; BLUEBIRD13/GETTY IMAGES

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We're proud to have started publishing stories in our Greenlight Project: a year-long look at how regional Australia is dealing with climate change. People living and working outside Australia's cities faces huge risks and equally huge opportunities through the challenges posed by moving to a low-emissions future. How will they fare?

Our dedicated Greenlight team is going bush, to tell stories from across the nation about the people, places and industries working towards that future: facing climatic change and innovating to confront it.

Please join us – there's much to learn.
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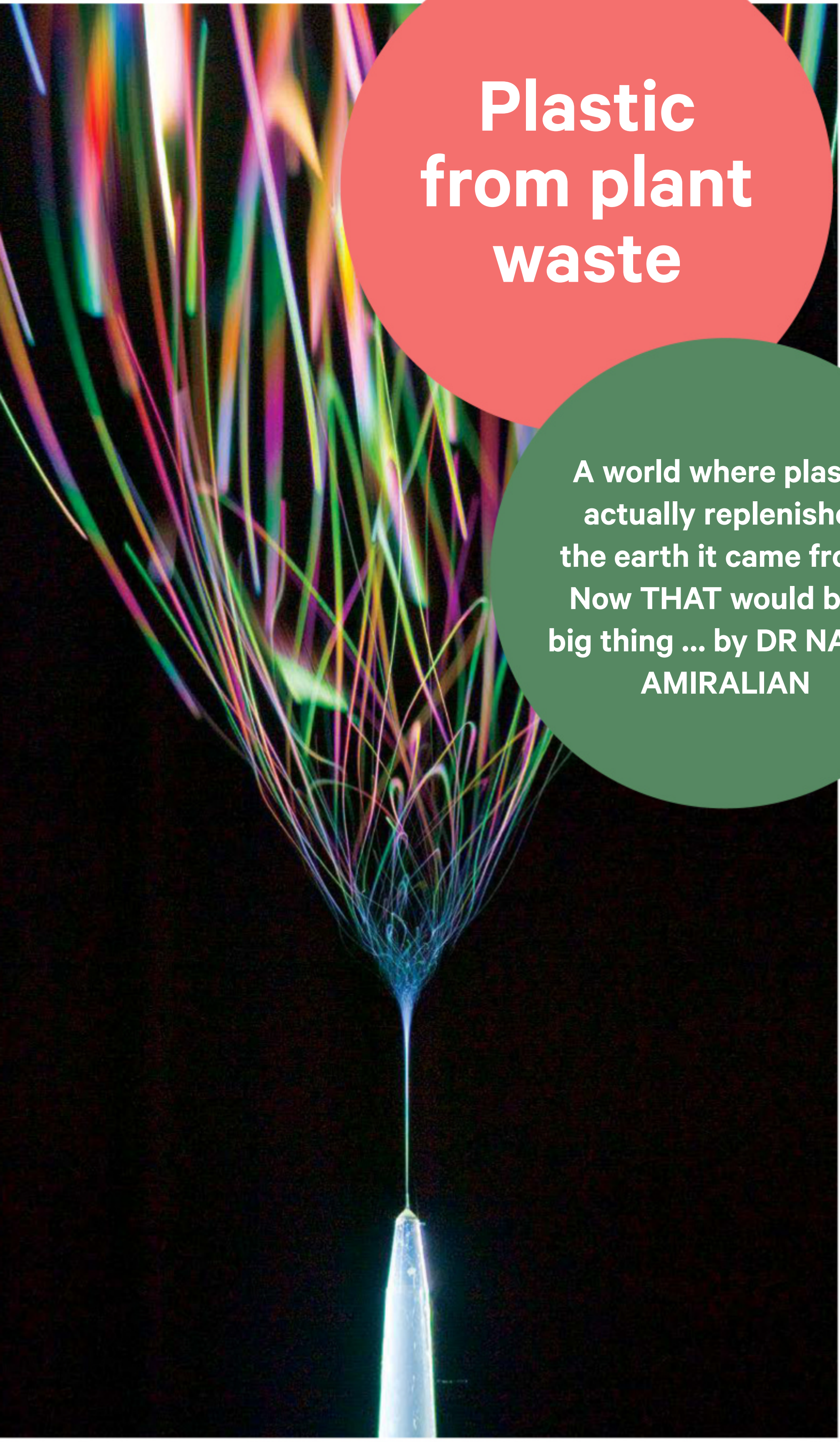
Plastic from plant waste

A world where plastic actually replenishes the earth it came from? Now THAT would be a big thing … by DR NASIM AMIRALIAN



WIKIPEDIA COMMONS

When I came to Australia, I started a PhD to work on Australian spinifex grass. At the time there was no science to understand its complexity, so my research was totally exploratory, working in collaboration with Indigenous Australians. What I discovered was a unique type of nanofibre that can be easily extracted from this grass. Since that discovery, we've developed a range of different applications. Based on this discovery, Australia now has a pilot production facility.

Different industries have a need for these types of nanofibres. And since my PhD, I've been able to extract them not only from spinifex but from other kinds of agricultural waste. This is my big passion – I can now extract the raw material from agricultural and textile waste and introduce new functionalities for them. Here in Queensland, we have plenty of sugarcane, banana and pineapple waste. I'm planning to turn it into very valuable products.

They can be used as plastics for packaging material, for instance. I'm also working on a project to replace plastic face masks with a smart biodegradable material. Plastic pollution is a monumental issue – this is the time to take action. My team and I are working toward that.

These nanofibres look like a human hair – but 10,000 times smaller. We can't see them with the naked eye, but depending on how you extract individual fibres, some of them are five times stronger than stainless steel. Because they are the building blocks of plants, they have great mechanical properties when you add just a tiny amount to other materials.

When you recycle a cardboard box, for example, its strength properties decrease. But by the addition of small amounts of these nanomaterials, we can significantly improve their mechanical properties.

We can also significantly improve the mechanical properties of plastic. There are many other applications for these nanofibres in other industries such as health, textiles, and flexible electronics.

Dr Amiralian's initial PhD saw her develop the technology to easily extract a unique form of nanofibre from common spinifex grass. Her discovery is now being used to extract valuable materials from agricultural and textile waste

JOUAN / RIUS / GETTY IMAGES

The beauty is that the nanofibres are natural and they biodegrade. It's cellulose – exactly like the paper that we write on. We've already made a bioplastic out of sugarcane waste. It has a very different structural composition, but can be used for packaging material to improve the shelf life of fresh food. We're also investigating including many other kinds of smart features into these materials, such as anti-microbial properties.

I've received significant interest from different industries. If you look at the agriculture sector, the waste ends up going into landfill, or it's burnt – we're just not doing anything with most of it. It's a problem.

I've always enjoyed fixing things. Probably the first big driver for me came from my family. They strongly encouraged us to go for higher education, and always try to have some positive impact on other people's lives. It was that combination that led to my passion to work at a university, because it's an educational place and I hope I can have a bigger effect and influence the younger generation.

It hasn't been easy for me to get a PhD scholarship because of the political challenges. My PhD scholarship was rejected several times because of sanctions and all those things. It was a very challenging time.

When I got a PhD scholarship from The University of Queensland, at first I set out to study the spinifex resin, but I knew I had to make my research have an impact to change my future. So I introduced a new direction to my project. I thought that because this grass grows in a very harsh environment, where the climate is hot and dry, it should have a different kind of strategy to survive these conditions. I had to convince my advisory team by doing some preliminary experiments, but they accepted my shift in direction.

I now do some teaching, but I do a lot of mentoring. I try to talk openly about all the challenges that I have faced to be in this position. I found that a lot of people relate, especially when they come from a different culture and a different language as I have.

When I came to Australia, I faced the challenges of how to adopt Australian culture and my organisation's working culture while still embracing my own culture. I happily share this experience with younger researchers, and hope I can help some people from overseas to find their career, so that when they have a dream, a passion, I can help them achieve it.

I am a strong advocate for cultural diversity and equity, and I try to support staff and students to grow as more effective leaders and create social good.

The reality is that university work is very challenging. You need to have a passion for science and the drive to make a positive impact. I call it a 24/7 job, because your mind is always busy.

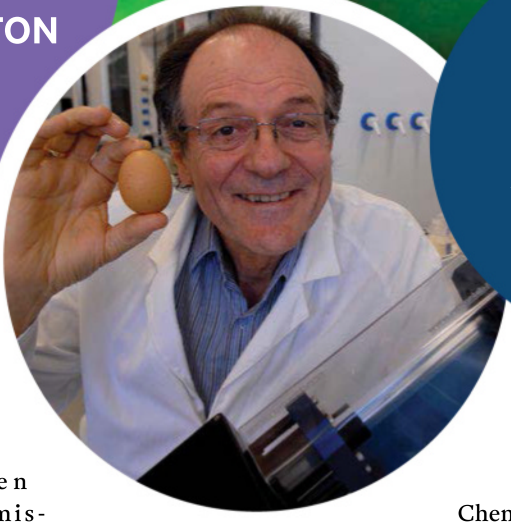
Not everyone necessarily needs to stay in academia – there are great opportunities to work in other sectors such as industry and government. Educated people can be successful there as well. It is important to find what you want and then go for your passion. ◉

> **The beauty is that the nanofibres are natural and they biodegrade. It's cellulose – exactly like the paper that we write on.**

DR NASIM AMIRALIAN is Group Leader of Bio-inspired Materials research at the Australian Institute for Bioengineering and Nanotechnology, University of Queensland. Her pioneering research uses a nanocellulose platform technology to develop innovative materials for diverse applications.

Fluid thinking saving the planet

The revolutionary vortex fluidic device (VFD) has the world of chemistry in a spin, writes COLIN RASTON



In 2015, Professor Raston was awarded an Ig Nobel Prize "for inventing a chemical recipe to partially un-boil an egg." Today, the VFD (right) is being used in hundreds of applications, with no end in sight

I wanted to make a difference and 25 years ago I completely embraced the concept of Green Chemistry. The idea says, "Let's start all over again and make chemistry 'benign by design'."

As chemists, we can't just keep doing more of the same without regard to the environment. Enough's enough. And I think society finally gets it. Despite what some politicians were trying to tell us even a few years ago, climate change is real – it's measurable. We've got bushfires and floods. And we've got plastics in the environment and in the oceans.

In chemistry, it's gone from being almost like a moral obligation to go down that green path to a question of time before it's a legal obligation.

The 12 Principles of Green Chemistry, laid out by Paul Anastas and John Warner, say that you don't just tweak a process to make it cleaner, because you only get so far – you're still going to generate waste if you use the same toxic reagents in your process. Green Chemistry is not a band-aid approach. It's making sure that we don't create something that has a negative impact on the environment, and is sustainable. When it was first proposed, it was a paradigm shift, and as president of the Royal Australian Chemical Institute, I helped get a lot of people involved. That ultimately led to securing the Australian Research Council Centre of Excellence in Green Chemistry.

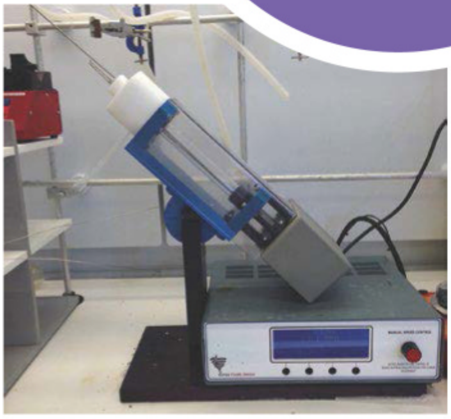
Globally, it's now a big movement. These days, if you're doing any kind of chemistry and applying to a funding agency, and you don't take on board the principles of Green Chemistry, it's highly unlikely you will get that funding.

Early in my research in Green Chemistry I was interested in applying these green concepts into continuous flow processing. It's a no-brainer: if you're doing your research and you pass some liquid through a reactor and it's flowing through and flowing out, then you can do all the fundamental science, and guess what? Unlike batch processing, it's got scalability already factored into it from the outset, so that the same research device can be your processing device. This way you can fast-track production, potentially bypassing the pilot stages that you'd normally have to do for conventional batch processing.

I was thinking about trying to make nanomaterials under continuous flow, and

ISABEL PAVIA / GETTY IMAGES

Understanding how fluids flow has been one of the great unsolved questions of science.



VORTEX FLUIDIC TECHNOLOGIES

I wanted to do it by applying clean mechanical energy rather than adding any kind of auxiliary chemical. And that ultimately led to the design of the vortex fluidic device – the VFD. This is the device that won me and my colleagues the Ig Nobel Prize in 2015.

Understanding how fluids flow has been one of the great unsolved questions of science. Now, by understanding how liquids flow in our vortex fluidic device, simply by applying mechanical energy, we take a huge step forward. The application potential is immense.

We recently published a paper in *Chemical Science* showing how immiscible liquids behave at very small dimensions. Immiscible liquids are the ones you don't normally think of mixing – like oil and water. But we showed how the VFD can mix immiscible fluids down to nanometre dimensions. It took over 100,000 experiments to figure it out, but the consequences are huge. We're making emulsions with implications for everything from drug delivery to salad dressings.

We published on this recently in *Nature: Science of Food*. We put nanoparticles of fish oil into apple juice. If you use a homogeniser, then everyone can taste and smell the fish oil. But if you make it at nanometre scale in the VFD, kids can't tell the difference between drinking apple juice and drinking apple juice with all the good Omega 3 in it.

So, what's the VFD? It's basically a rotating test tube with a little lip at the top, and you tilt it off axis at 45°. You've got liquid in there, and then you introduce spinning mechanical energy into that liquid. Now you've got the maximum cross-factor gravity pushing down, and you have centrifugal force holding the liquid against the tube.

The device is only 20mm in diameter and about 20cm long, but you can build bigger units for high-volume processing. That's all it is. You can have jet feeds delivering reagent liquids to the inside of the tube. And as they're whirling up and coming out of the tube, they're undergoing all these changes. This is your continuous flow process.

With this device, you get the formation of Faraday waves in the liquid, and you get Coriolis forces from the base of the tube. And all this mechanical energy is imparted down to less than one micron in dimension regimes. Knowing this is the key to all these other wonderful applications.

With the VFD we can partially unboil an egg, which we do by refolding proteins. Protein folding is a huge deal for the pharmaceutical industry. We've also been able to accelerate a variety of enzymatic reactions, which is another big deal.

A paper has just come out showing how we can make graphene oxide. There are lots of applications of graphene oxide, but the way they traditionally make it uses concentrated sulfuric acid and toxic metals. We've developed a process using our VFD with close to zero waste. All you need is aqueous hydrogen peroxide and graphite. We call it GGO – green graphene oxide. It's trademarked.

We've also published work on using the VFD to extract DNA out of extinct species that have been preserved in formalin. Some of these species are over 150 years old.

We are using the VFD to amplify the detection of biomarkers. Initially, it was focused on COVID-19 – a test that took four hours comes down to four minutes in the VFD. In the future there are some good applications of the VFD in wine processing because you're not adding chemicals. At certain processing parameters, we can cut carbon nanotubes down to specific lengths for applications in devices. That's very big too.

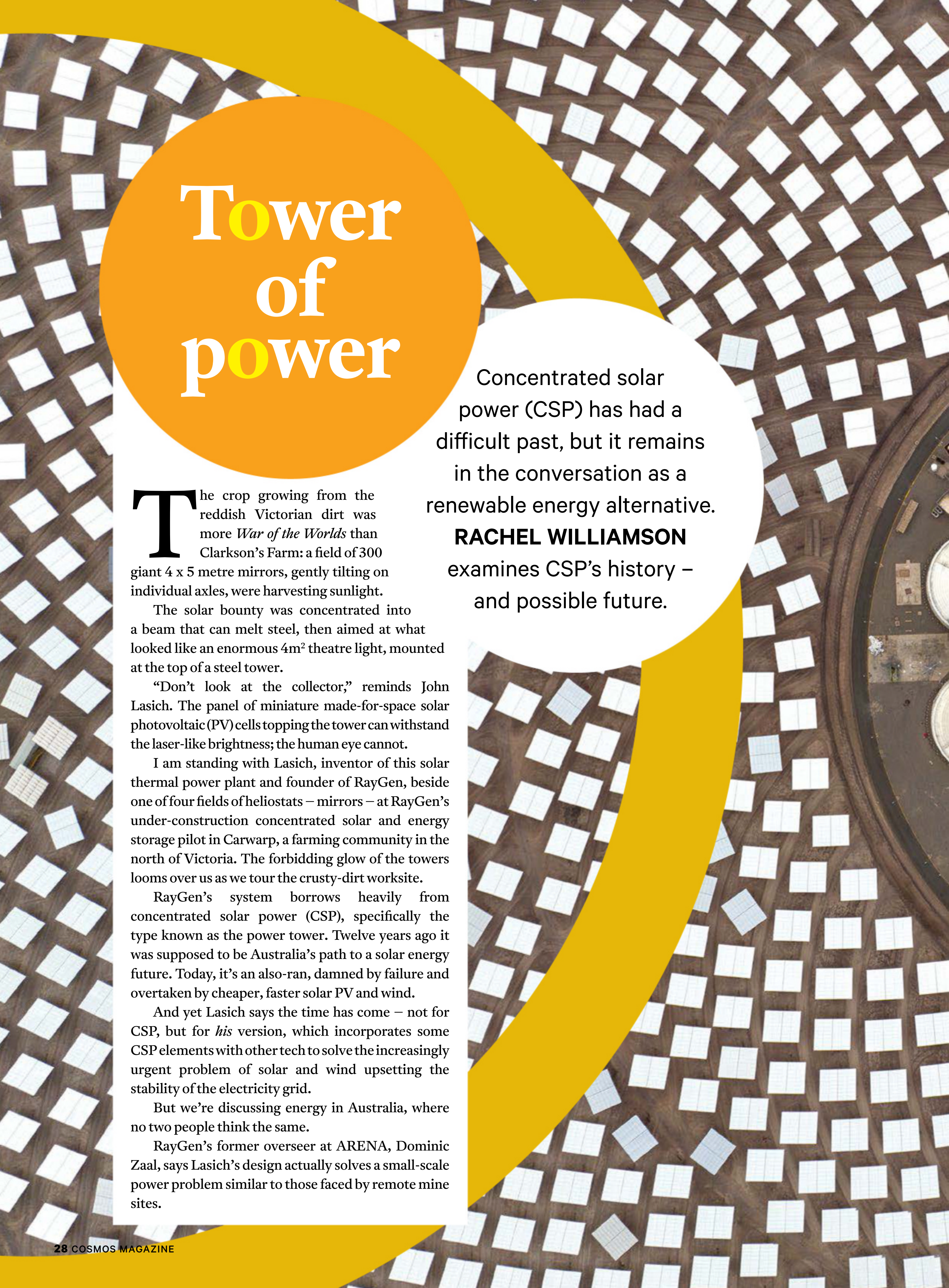
Because we now understand the fluid flow in the device, it's accelerating more and more applications. Even though we've published over 100 papers on applications of the VFD, we still haven't got to the end of the beginning.

My interest in chemistry "exploded" in year 12 at John Curtin High School in Perth in 1967. My chemistry teacher blew my mind. He was very young – Mr Stockdale. He'd been teaching in the country, but he came to Curtin – and he just had it all together.

Our school overlooked Fremantle Harbour, and at the time they were blasting for a deep water channel. We would look out the classroom window and periodically see these massive plumes of water going up after these explosions. And he'd say, "Oh, I can do better than that."

He'd then set up experiments that were very exciting. But afterwards we'd sit down and go through all the chemistry to explain it. It was then I realised that if you completely understand your chemistry, you understand your surroundings. I haven't looked back. ◉

COLIN RASTON AO FAA is Professor in Clean Technology at Flinders University. He is a former President of the Royal Australian Chemical Institute. He is a champion of Green Chemistry.



Tower of power

Concentrated solar power (CSP) has had a difficult past, but it remains in the conversation as a renewable energy alternative. **RACHEL WILLIAMSON** examines CSP's history – and possible future.

The crop growing from the reddish Victorian dirt was more *War of the Worlds* than Clarkson's Farm: a field of 300 giant 4 x 5 metre mirrors, gently tilting on individual axles, were harvesting sunlight.

The solar bounty was concentrated into a beam that can melt steel, then aimed at what looked like an enormous 4m^2 theatre light, mounted at the top of a steel tower.

"Don't look at the collector," reminds John Lasich. The panel of miniature made-for-space solar photovoltaic (PV) cells topping the tower can withstand the laser-like brightness; the human eye cannot.

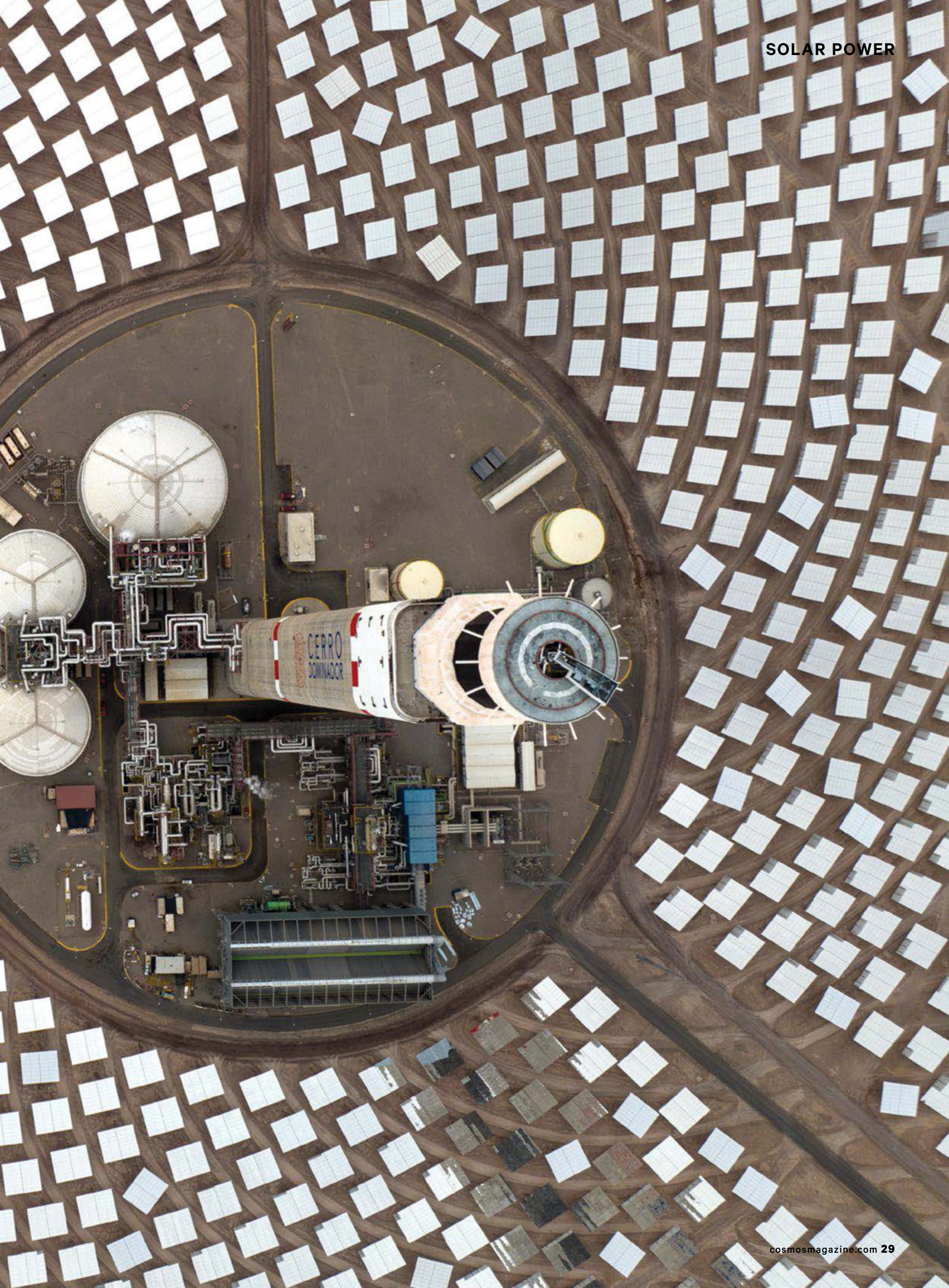
I am standing with Lasich, inventor of this solar thermal power plant and founder of RayGen, beside one of four fields of heliostats – mirrors – at RayGen's under-construction concentrated solar and energy storage pilot in Carwarp, a farming community in the north of Victoria. The forbidding glow of the towers looms over us as we tour the crusty-dirt worksite.

RayGen's system borrows heavily from concentrated solar power (CSP), specifically the type known as the power tower. Twelve years ago it was supposed to be Australia's path to a solar energy future. Today, it's an also-ran, damned by failure and overtaken by cheaper, faster solar PV and wind.

And yet Lasich says the time has come – not for CSP, but for *his* version, which incorporates some CSP elements with other tech to solve the increasingly urgent problem of solar and wind upsetting the stability of the electricity grid.

But we're discussing energy in Australia, where no two people think the same.

RayGen's former overseer at ARENA, Dominic Zaal, says Lasich's design actually solves a small-scale power problem similar to those faced by remote mine sites.


CERRO
DOMINADOR

RayGen competitor, Vast Solar, says *it* is solving the grid problem with new-and-improved traditional CSP.

BloombergNEF (new energy finance) analyst Jenny Chase says the grid problem is already being solved with lithium-ion batteries; CSP, she says, is for men with an engine "fetish".

Energy expert Tristan Edis denies grid stability is a problem at all.

The day may be arriving when CSP technology can claim its place in Australia's factionalised renewable energy tableau, but it must first prove one thing: that it can work.

RayGen's Carwarp site has 300 mirrors that swivel to maximise sunlight for delivery to its "power towers."

CSP's chequered past

There are several forms of CSP, but the one deemed most suitable for Australia is the power tower. Sunlight is concentrated onto a tower-top receiver, heating molten salt to 560°C. That salt flows back through pipes to a heat exchanger, which boils water into steam to turn the same kind of turbine used in coal power plants. The "battery" element is a hot tank that can feed super-hot molten salt to the heat exchanger over a period of many hours, and a cold (290°C) tank that feeds the heat-sapped liquid back to the tower.

In Australia, only Vast Solar's 1.1 megawatt (MW) demo at Jemalong, NSW, has succeeded, and only with an eye-popping price tag of $US14,919/kilowatt (kW), according to data from the US National Renewable Energy Laboratory (NREL). Globally, only six gigawatts (GW) of CSP has been installed commercially – and only 1.3GW of that is power tower, NREL data shows.

Technical problems have plagued the technology: including molten salt busting tanks open, and cloud-induced dips in sunlight wreaking havoc. But the idea is rising again. RayGen's Carwarp sun farm is already sending 4MW of PV power into the local grid as it finishes the 8MW turbine-and-thermal-storage backend and tests the computerised controls that will bring the whole complex machine together.

And it *is* complicated: the mini PV panels (100 times more expensive – but 1000 times more powerful – than a regular PV panel) generate normal solar power for the grid, but also heat. Water that flows behind the collector to keep it cool is heated to 90°C and piped back to a 16,000m^3 'hot' pit. It can then be used at will to boil ammonia (which has a boiling point under 90°C) to turn a turbine to generate as much as 17 hours of non-solar power. The cool water is held in a cold pit, ready to be "charged" again.

Vast Solar is yet to turn a sod on its newly acquired Port Augusta site in South Australia, but is confident this time it will be the winner, using new salt storage technology and software to maintain the 100% accuracy required from its heliostat targeting system.

CSP is not the only frontier energy storage idea Australia is having a go at. A massive compressed-air system is pencilled in for Broken Hill, in western NSW; Swiss whizzes want to build a gravity battery in Townsville, Queensland; and the Mars factory in Wodonga, northern Victoria, has signed up to a graphite battery. But CSP is the best cautionary tale to date for what can happen if the new technologies fail to live up to their promise.

Australia's first flirtations with power towers were in Queensland in 2011, when a French company pitched a $1.2 billion, 250MW project called Solar Dawn, and a demo plant separately launched at the Kogan Creek power station, near Chinchilla. Solar Dawn was scuttled the following year after failing to raise enough money, and Kogan Creek in 2016 after years of technical problems.

Around the same time, researchers at thinktank Beyond Zero Emissions analysed Australia's alternatives to coal and gas power and landed on CSP. The starting place for their campaign was Port Augusta.

Coal had been good to Port Augusta, but left a terrible legacy. From 1954, three power plants employed generations of workers, but in early 2012 Playford B, the country's dirtiest coal plant, was mothballed. Its neighbour, Northern Power Station, ran for three more years and took hundreds of jobs when it closed. In March 2015, Beyond Zero Emissions director Mark Ogge was called in to present to a sceptical Port Augusta council.

PREVIOUS SPREAD: JOHN MOORE / GETTY IMAGES. ABOVE:

The sun-collecting, curved heliostats range in size from the large to the huge. Typically more than 20m^2, some in development are reaching the 150m^2 mark.

VAST SOLAR

“We finished the briefing and there was this stony silence,” he says. “One councillor said, ‘what about the cost of this?’ And [mayor] Joy Baluch goes, ‘well, what about the bloody cost of people in hospital with lung cancer, councillor?’ And at that moment I realised we had a powerful ally.”

Baluch’s husband died of lung cancer, which she attributed to his job at the power plant; she died in May 2013 from breast cancer. Official statistics from 2010 showed Port Augustans had a lung cancer rate double the SA average. A “cancer atlas” produced in 2012 by the University of Adelaide for the SA Cancer Council shows lung cancer rates in Port Augusta remained at above average levels for years.

Between 2012 and 2017, a grassroots lobby called Repower Port Augusta Alliance campaigned to bring a CSP project to the town. Chair Gary Rowbottom, who worked in the power stations, believed it would provide the jobs “the normal mechanical sods among us” would need when coal-fired generators closed. Their champion? US company SolarReserve, introduced to Port Augusta by Ogge’s team, which in 2017 proposed to build a copy of their $US1 billion, 150MW Nevada plant, to be christened Aurora.

But to get even that far SolarReserve had already made compromises that would prove fatal. To get the project off the ground, the company won a tender to sell power to the SA government. But it was forced to undercut bidders with cheaper alternatives, such as solar PV, with a maximum $78/MWh price.

According to BloombergNEF’s Jenny Chase, 2022 prices for low-cost solar PV backed by a four-hour battery in Australia start around $60/MWh; the global CSP light-on-the-hill, the Cerro Dominador project in the Atacama desert in Chile, sells power for $US114/MW.

SolarReserve had also secured $110 million in low-interest loans from the federal government, but private investors couldn’t be convinced to back it. Not only were they sceptical of SolarReserve’s ability to make the low-low price turn a profit, but the company’s Nevada plant was struggling with a crucial problem: engineers couldn’t figure out how to stop the 560°C molten salt from melting the hot tank.

Other assumptions behind the Aussie plant didn’t add up. It was supposed to produce almost three times as much power as the Nevada plant for less than half the cost, but from a less favourable location and with two hours less storage, wrote Alberto Boretti, a former RMIT scientist and now dean at Prince Mohammad Bin Fahd University in Saudi Arabia, in a paper last year.

China is the one to watch ... It has 28 CSP projects pencilled for launch in 2023 and 2024.

“To expect [this performance]... was contemptibly optimistic. No investor, therefore, decided to risk [sic] on this project.”

By 2019 the Aurora dream was over. SolarReserve went bankrupt the following year.

Now, VastSolar is relaunching Aurora and plans to build a 30MW CSP plant on the site, using that federal government funding. It’s still looking for the final $70 million to cover its $180 million cost.

The current position

Sunny countries around the world are increasingly littered with fields of mirrors glinting at towers, parabolic troughs and linear fresnel systems.

The US has two operational CSP plants – the 377MW Ivanpah in the Mojave Desert, California, and SolarReserve’s Crescent Dunes in Nevada, which reopened after it solved the leaking molten salt problem with new types of welds for the holding tanks. More recently plants have been built in Morocco, the UAE, Chile and China.

Chile is the bright shining light of the industry. The 110MW Cerro Dominador project is a hybrid of CSP and 100 MW of solar PV; its molten salt storage can provide a whopping 17.5 hours of power.

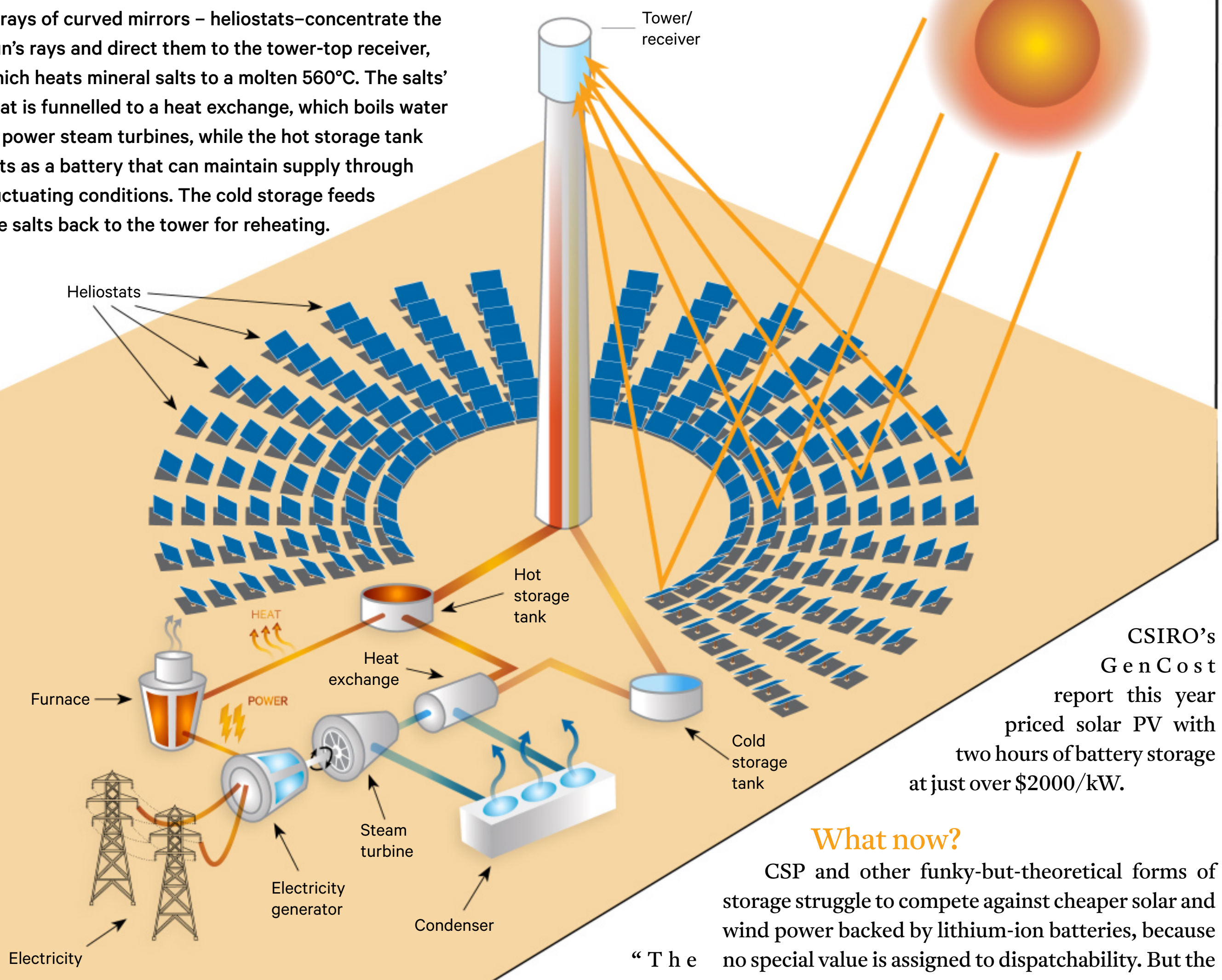
The project cost $US1 billion to build. Last year the company entered Chile’s energy action with a second project, a three-tower CSP site in the north with a record low sub-$US34/MWh price.

Yet because Chile, like Australia, does not yet place a special value on dispatchable power – the ability to send ‘firm’ power into the grid at any time other than when it’s made – it lost that tender.

China is the one to watch, says Dominic Zaal, the director of the Australian Solar Thermal Research Institute (ASTRI). It has 28 CSP projects pencilled for launch in 2023 and 2024. Currently NREL data shows eight operational power tower projects in China, but the country has also consistently undershot its own five-year-plan goals for installed CSP, something it rarely does in any other field.

CSP: HOW IT WORKS

Arrays of curved mirrors – heliostats–concentrate the Sun's rays and direct them to the tower-top receiver, which heats mineral salts to a molten 560°C. The salts' heat is funnelled to a heat exchange, which boils water to power steam turbines, while the hot storage tank acts as a battery that can maintain supply through fluctuating conditions. The cold storage feeds the salts back to the tower for reheating.



“The Chinese government said wind and PV are creating problems because they're intermittent generators, just like is happening in Australia,” Zaal says. “So what did the Chinese government say to fix that? They said if you want to put PV or wind into the system, you have to have 20% of that in long duration energy storage.”

But China can also build CSP towers at a price that would make them competitive in Australia, Zaal says – $US3000 per kilowatt – and make money selling power for $US70/MWh. NREL historical data shows construction costs in the $US3000–5000/kW range.

Wood says Vast Solar's iteration of Aurora will cost $6000/kW – a considerable saving on the $22,000/kW NREL cites for its Jemalong plant. RayGen's Carwarp site will cost $30 million, but commercial manager Dr Kira Rundel says they don't have a breakdown of what that cost looks like at a per kilowatt level. However, she says the next project, a 300MW solar/150MW thermal storage plant in Yadnarie on the Eyre Peninsula, will cost $1400/kW for the solar farm and $2000/kW for the 24-hour thermal storage.

CSIRO's GenCost report this year priced solar PV with two hours of battery storage at just over $2000/kW.

What now?

CSP and other funky-but-theoretical forms of storage struggle to compete against cheaper solar and wind power backed by lithium-ion batteries, because no special value is assigned to dispatchability. But the time may be coming in Australia when this kind of electricity does come with a value. As more coal power plants are shut down, there's a view that these need to be replaced with something similar. And this is where CSP could play a role, says Simon Corbell, the chair of the Clean Energy Investor Group.

“There will be a need for more dispatchable generation,” he says. “Potentially solar thermal will help meet that need. The commercial case will continue to strengthen and investors will be watching that closely, particularly if there is also the development of new markets that incentivise dispatchable energy, such as some kind of capacity mechanism in the National Energy Market.”

That could mean a kind of Renewable Energy Target for stored energy, the subsidy that allowed wind and solar to take off from 2001.

Right now, companies like RayGen are positioning themselves in the witheringly dubbed “rhombus of regret”, the area around Mildura where a lot of intermittent wind and solar is packed close to an electricity grid that isn't set up to transport it all. That's led to massive curtailment – when the energy market operator stops wind and solar farms from selling their energy because the infrastructure can't handle it.

GREG BARTON

Vast Solar's concentrated solar thermal power modules are made up of 700 mirrors.

VAST SOLAR

Batteries are sneered at as a solution, because even the large-scale ones are designed to hold only up to about four hours of power. Yet, Price says, this is how the US is solving its grid+solar+wind problem.

Experts in Australia are cautious.

"Every time I've looked into CSP the point I've got to is there is a charismatic and persuasive and very dedicated engineer who's invested considerable time and effort in this and really believes in it," says energy economist Bruce Mountain, inaugural Director of the Victoria Energy Policy Centre.

"In an environment where governments are really keen to dedicate funding to new projects, they've obtained funding, and then they've struggled. But it's great we can afford to try these things so we really shouldn't stop. The benefit of the doubt should be given to those who have an idea that has some promise."

Climate Council senior researcher Carl Tidemann says despite its troubled history, CSP is promising. "It's been misunderstood as to what its role is. It's been compared directly with solar [PV], which has won the cost race for generating electricity, as have batteries in some ways," he says.

"If we hope to get off gas and coal completely we need longer-term storage. You can install as many batteries as you like, but they're not going to provide enough hours of storage to really start to displace coal and gas power."

> "If we hope to get off gas and coal completely we need longer-term storage."

But what if Australia doesn't need long duration storage? What if, as Price says, the solution is just add another battery? Supply chains for lithium-ion components are broadening and cleaning out undesirable metals, and the large-scale market for them is growing faster than anyone expected.

A simulation from global renewable energy developer Windlab that scales up wind and solar and pumped hydro in the NEM suggests Australia can get away with just five hours of storage for all but a few weeks of the year.

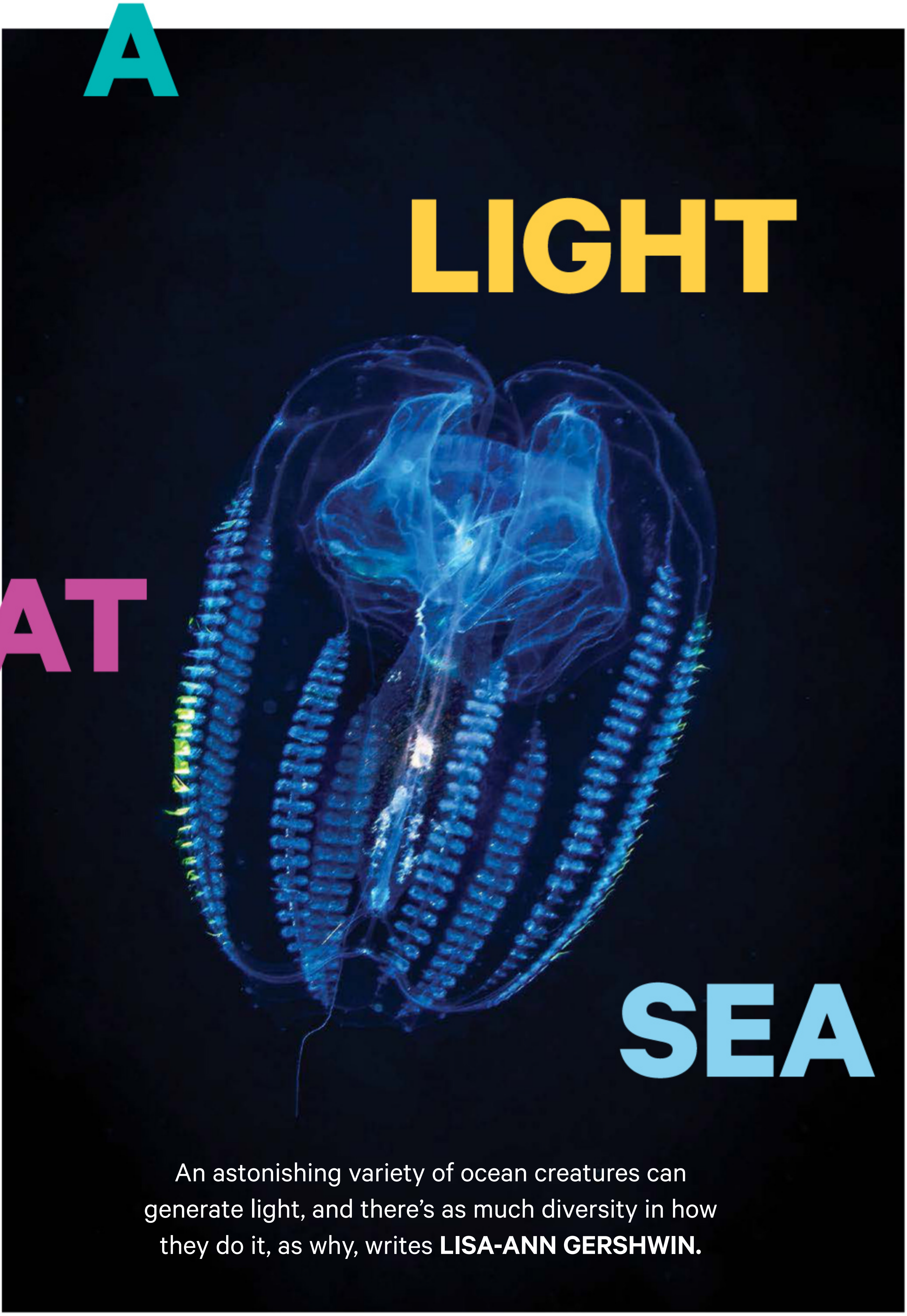
"The case for long-duration storage has been that a bunch of people desperately want to believe that we will need it," says Green Energy Markets director Tristan Edis. "We don't need a lot of it. It's quite conceivable it could well be a bunch of biofuels sitting in storage tanks next to a gas turbine. CSP is not cheap per megawatt. What you want is cheap capex [capital expenditure]; and spend a lot on the fuel because you don't use it very often."

Concentrated solar power may still be the white elephant. And yet, without enthusiasts willing to keep niggling at the problems, we'll never have the chance to see if it could work in Australia.

As Repower's Gary Rowbottom put it: "It's safe to say 'it'll never happen' and be sceptical, because if it doesn't you can sit there smugly and say 'I told you so'. But it takes a bit of guts to advocate for something that's a little difficult." ◉

RACHEL WILLIAMSON is based in Melbourne. Her last story, on chronology, appeared in Issue 91.

A LIGHT AT SEA



An astonishing variety of ocean creatures can generate light, and there's as much diversity in how they do it, as why, writes **LISA-ANN GERSHWIN.**

LEFT: JAMES GARLICK. RIGHT: RIBEIRODOS SANTOS / GETTY IMAGES

Visitors to the Uffizi Gallery in Florence, Italy, may be so overcome with emotion in the presence of great art that they sometimes experience fainting, hallucinations, and palpitations – a cluster of symptoms known as Stendhal Syndrome. But these feelings of intense wonder and awe are not just limited to famous paintings and sculptures.

An eerie glow where the waves break. A flash beneath our feet at the water's edge. Tiny dots of light on our skin. The balmy summer heat reminds us that it's beach-time, and those who linger after dark are often rewarded with visions of great delight. Glows of light. Flashes so bright.

Bioluminescence, or "living light", has intrigued humans for thousands of years. Aristotle wrote about sparks in the sea, marvelling at how these fires were not extinguished by water.

Bioluminescence is light made within the bodies of organisms. This cool light – in both meanings of the word – gives off very little heat, and it's fascinating. The chemical reaction is similar in principle to that of a glow stick: two chemicals meet in the presence of oxygen, resulting in light. In organisms, these two substances are substrates generically known as luciferins and enzymes generically known as luciferases (both derive their names from the Latin *lucifer*: light-bearer).

Different colours of light are produced by changes in the polarisation and microclimate of the luciferins, as well as by mixing and matching with structurally different luciferases. These different colours are generally associated with habitat, with pelagic and deep-sea species generally emitting blue light, coastal marine species more often shifted toward green, and terrestrial and freshwater species typically shifted into yellow. There are deviations, however, such as the terrestrial railroad worm (*Phrixothrix hirtus*), which displays two rows of yellow-green lanterns along its body, plus two red lanterns on its head.

Ctenophore comb jellies (previous page and opposite) flash brightly using 10 different forms of proteins. Tomopterids (above) spend their life in the water column and, in addition to their body glow, they have the as-yet unexplained ability to emit yellow bioluminescent mucus. Bioluminescence in cephalopods (below), such as this squid, can appear as dots and stripes and appears to be utilised as a means of communication.

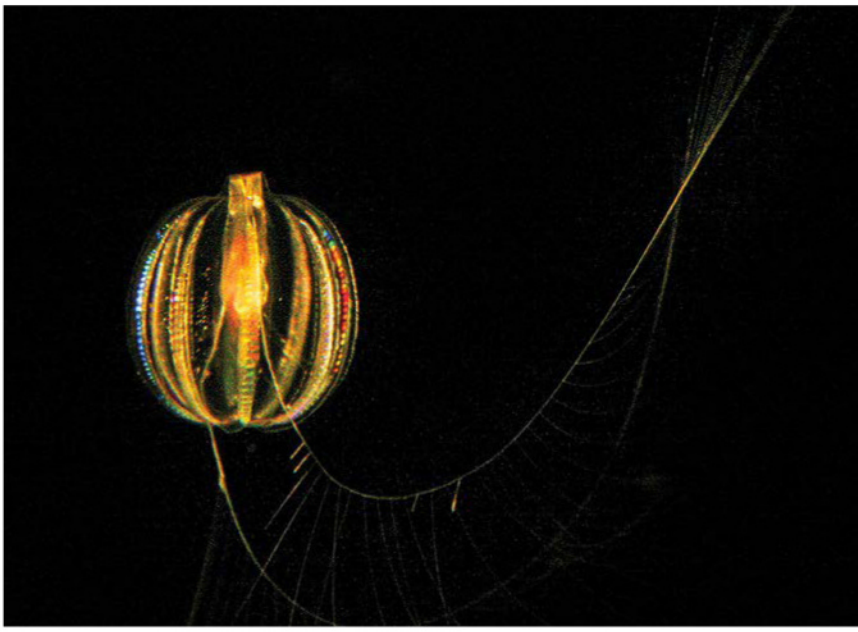
At least 11 different types of luciferins are known, along with dozens of associated luciferases, suggesting that bioluminescence has evolved independently many different times on the tree of life. In fact, recent studies have estimated this figure to be at least 94 times, and one study found that light production has evolved at least 27 different times in marine fishes alone. Luciferin-like proteins can even be found in some non-luminous species, and can be stimulated to produce light by exposure to luciferases.

Bioluminescence is more common than you might think. A 2017 study by the Monterey Bay Aquarium Research Institute, in California, found that bioluminescence occurred in more than 75% of the deep-sea animals observed over 17 years of video recordings. Indeed, in the inky darkness of this vast and alien realm – often called the twilight zone – bioluminescence is the dominant form of light.

Bioluminescence is found in more than 700 genera, including terrestrial plants, animals, fungi, and bacteria, and notably almost every marine phylum. So, if bioluminescence is so prevalent, it begs the question: why? And here is where the story becomes even more fascinating.

MANY SOFT-BODIED ORGANISMS give off a sudden flash when disturbed. The comb jellies (in the phylum Ctenophora) are flashers extraordinaire. There's *Beroe*, a pocket-shaped creature with teeth, whose fiery luminescence lights up its internal organs like the strobe of a skeleton at a Halloween party. *Cestum* and its diminutive cousin *Velamen* are belt-shaped creatures that swim essentially sideways, undulating two 'arms'. They, too, are brilliantly luminescent in split-second responses to threats. Even *Mnemiopsis*, one of the world's most invasive species, reveals flashes through the body.

ALL ICONS: PHYLOPIC. FAR LEFT: THIERRY EIDENWEIL. ABOVE: NOAA / MONTEREY BAY AQUARIUM RESEARCH INSTITUTE



Surprisingly, one of the phylum's most delightful creatures, *Pleurobrachia*, which performs a series of twirls and somersaults to get food from its tentacles to its mouth, is one of the few incapable of glowing.

FLASH LUMINESCENCE IS also common in cnidarian jellies (the ones that sting, stemming from the Greek *cnida*, meaning nettle). For example, many siphonophores – a group of strange colonial jellies including bluebottles – have evolved ways of using light as scare-tactics, lures, or mimics of other species. One of the most fascinating is the deep-dwelling species *Erenna*, which characteristically twitches red-glowing filaments as a lure for small fish.

ANOTHER REMARKABLE MEDUSA is the elegant crystal jelly *Aequorea victoria*, which flashes a brilliant blue along its internal canals and the margin of its bell. *Aequorea* is better known for tiny fluorescent spots at the base of its tentacles that glow almost radioactive green under ultraviolet (UV) light; research on these proteins led to the 2008 Nobel Prize in Chemistry. Intriguingly, instead of the typical luciferin–luciferase system, *Aequorea* uses a photoprotein to generate its bioluminescence. A photoprotein is a stable complex of a protein and a substrate, wherein the luminescent reaction is activated by calcium or iron ions rather than oxygen. More than 10 photoproteins are currently known.

A VARIATION ON this single flash is a propagation of flashes, such as in the pyrosomes (Latin for fire body), strange colonial tubular sea squirts. When one member flashes, it triggers its neighbours and so on, creating a ripple-on-a-pond effect. These flashers are thought to act as a burglar alarm, scaring away would-be predators. Other variations on these flashes include the deep-sea crown jellyfish *Atolla*, in which the flash races around the body in a circular pattern, like a Formula One car on a racetrack, or the Santa's hat jelly, *Periphylla*, in which the whole body twinkles.

CRUSTACEANS ARE ALSO masters of bioluminescence, displaying either as a glowing cloud or as a steady internal or external light. For example, the sesame-seed-shaped ostracods, known as "fireflies of the sea", vomit up bioluminescence, creating a distraction in the water.

During World War II, the Japanese army issued packets of 'sand' to soldiers (actually dried ostracods). The soldiers would pour a bit of this sand into the palm of their hand, spit on it to activate it, then rub their hands together to have enough light to read their maps without giving away their location.

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Some prawns also create a glowing cloud, but this is less of a vomit and more of a spit. Either way, these clouds act as a smoke screen, allowing the organism under threat to escape undetected.

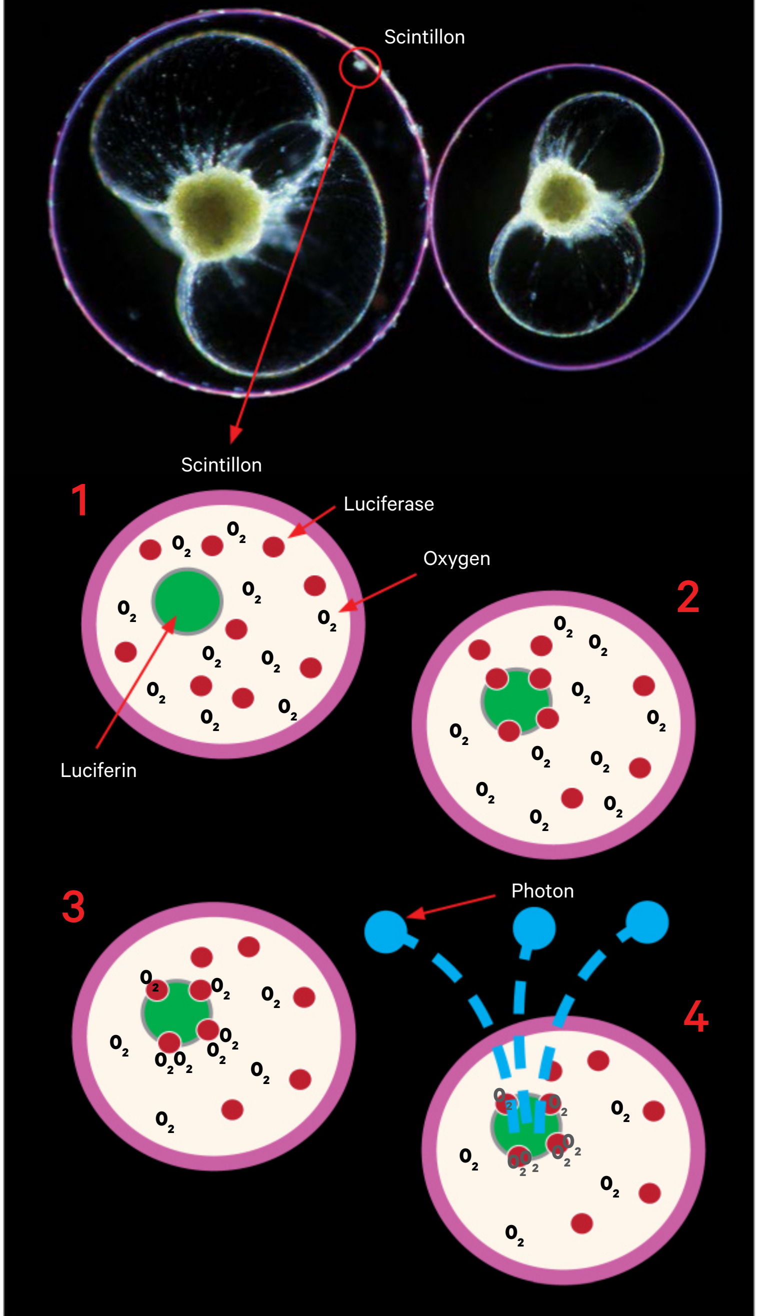
ANOTHER GROUP OF crustaceans, known as amphipods, are as dazzling in their luminescence as they are in their morphology. Forms range from little orange species the size of a pea, to ones the size of a wasp with a single elongated pointy eye that takes up half the body length, to ones even more elongated into the size and shape of a toothpick, to ones slightly larger than an avocado and so transparent that you can read newsprint through their body. Euphausiids, or krill, have tiny light organs called photophores distributed along the body.

MANY FISH ARE also able to glow. Some fish have photophores, which appear as lines of small silvery beads in species-specific patterns. Photophores are particularly common in the most abundant vertebrates on the planet – the fish-fry-sized bristlemouths – as well as in lanternfishes: big-eyed, charcoal-coloured, goldfish-sized, and of a disturbingly gelatinous consistency. If you're a deep-sea fish, no good can come from spending time with a species that can eat you or that you can't mate with, so photophore patterns may be one way to tell who's who.

ONE PARTICULARLY STRIKING glow strategy is that of the anglerfishes. Like something out of science fiction, these have a stalk protruding from their forehead bearing a cluster of bioluminescent wormy-looking appendages. Smaller predatory species are attracted by the lure of these glowing 'worms', which look like

TOP RIGHT: LISA BRIGHTFIRE / GETTY IMAGES

BIOLUMINESCENCE

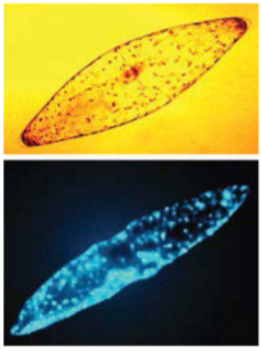


1: In dinoflagellates such as those above and below, bioluminescence is created by a luciferin-luciferase reaction in small pockets within the cytoplasm called scintillons.

2: When the dinoflagellate is agitated by water movement, the luciferase interacts with the luciferin.

3: This interaction acts as a catalyst for oxygen.

4: The ensuing chemical reaction creates oxyluciferin in an excited state; the oxyluciferin emits visible light as it returns to its ground state.



Scintillons (right) are visible as darker points in the 1mm long marine dinoflagellate *Pyrocystis fusiformis*, indicating where bioluminescence will occur.

food. The anglerfish gapes its enormous mouth, and the predator becomes the prey.

A variation on this is the monstrous-looking dragonfish, where the lure dangles from the chin, under a mouth so full of teeth that the fish can't even close its grin to conceal its weapons.

IN THE FLASHLIGHT fishes, light organs filled with luminescent bacteria blink on and off beneath the eyes, controlled by the fish to shut off the light at will with opaque 'eyelids'. Bony fishes, however, aren't the only ones who glow. Among the cartilaginous fishes, numerous types of sharks can also emit light, with at least four species able to do so spontaneously. The widely distributed kitefin shark (*Dalatias licha*), which inhabits sea-floor waters up to 600m deep and grows to nearly 2m in length, is the largest vertebrate – on land or in the sea – known to luminesce.

MANY LESS GLAMOROUS species can also glow. For example, gossamer worms are segmented like earthworms, but their bodies are gelatinous and transparent, like jellyfish, with dozens of paddle-like legs they use for swimming. These worms emit yellow bioluminescence as a flurry of sparks from the tips of their legs. Yellow bioluminescence is very rare in the deep sea. We are still at the dawn of understanding the biochemistry and biology underlying this unusual colour production; however, it's believed to occur through activation of nicotinic cholinergic receptors and calcium channels, and has been demonstrated to be under nervous control. The reason for this atypical expression is also unclear: the light has been interpreted by various authors as a deterrent, an attraction, an escape/defence response, or – as it's thought that other deep-sea species are largely unable to see yellow – perhaps a means of private communication between worms.

Another strange glowing creature is *Enypniastes*, a swimming sea cucumber. Normal sea cucumbers spend their lives sitting or crawling on the seabottom, but *Enypniastes* drifts along, aided by an umbrella-like veil, occasionally dipping down to pick up a mouthful of sediment before rising back up into the water column, where it digests the edible particles from among the sand grains. With minor disturbance, *Enypniastes* luminesces at the site of irritation, but if broadly impacted, the animal sloughs off its whole skin in a glowing mass.

POSSIBLY THE COOLEST of all cool-light species are the squids. Consider, for example, *Vampyroteuthis infernalis* (one of the best Latin names ever, translating to "vampire squid from hell"). Picture a quivering gelatinous mass

BELOW LEFT: EDITH A. WIDDER. TOP LEFT: OXFORD SCIENTIFIC / GETTY IMAGES

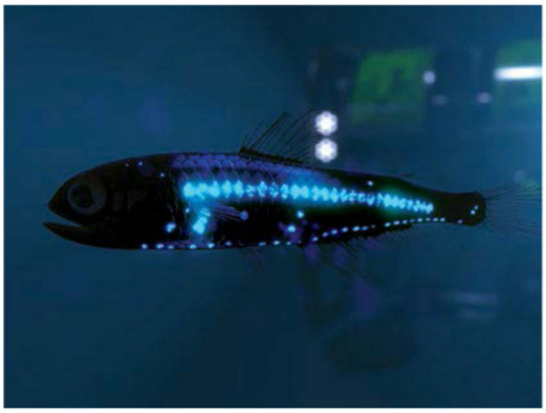
of dark-red goo (appearing jet-black at depth), with huge hauntingly blue eyes and with a web-like cloak covering its eight arms, each bearing numerous sharp hooks instead of suckers.

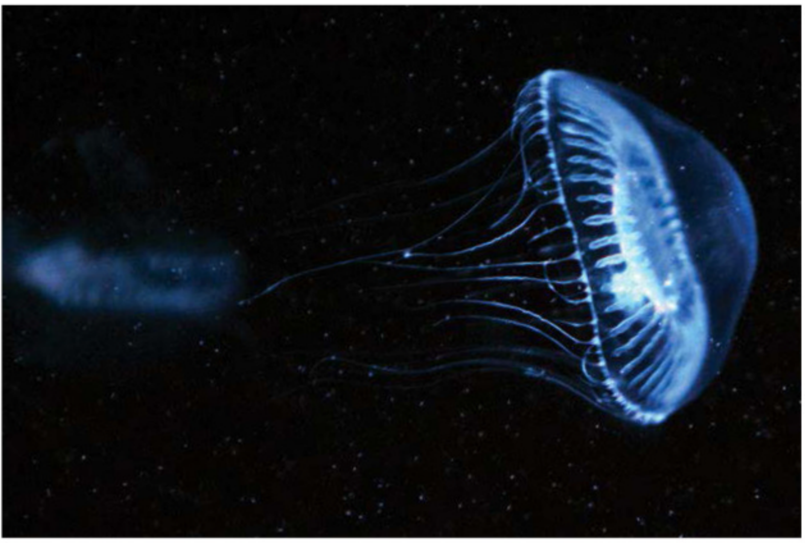
Close up, *Vampyroteuthis* looks like a bloodthirsty villain, but in truth it is actually a timid little creature. It lives in the parts of the deep sea where oxygen is at its lowest, known as the Oxygen Minimum Zone. Here, with nowhere to hide, and more vulnerable to predation than it looks, it has two different bioluminescence modes. In response to mild stimulation, the animal responds with glowing or flashing bright blue light at the ends of all its arms simultaneously. If stimulated more strongly, a viscous fluid laced with glowing particles is emitted from the tips of the arms. Movement of the arms disperses the particles, creating a glowing cloud around the animal.

AMAZINGLY, SOME SQUIDS have the ability to sense the downwelling light and match it quite perfectly with their own light, so that other organisms beneath them are unable to see their silhouette. They can even change their output on the fly, for example dimming slightly to match a cloud passing overhead. These squids are actually using bioluminescence for camouflage.

MOST OF US DON'T HAVE access to remotely operated vehicles or submarines to visit these denizens of the deep, but we can still see bioluminescence in action. Many zoos and aquariums exhibit flashlight fish with their blinky eyes or *Aequorea* in both its bioluminescence and fluorescence modes.

But the most wondrous experience is to play with sea sparkle at the beach. Not always, but often, summertime beaches come alive at night with blue vibrance akin to the signature hue of Avatar.





The glow show (above) of the lanternfish, includes light-producing photophores along its ventral surface (belly), and a nasal “headlight” organ. Research into aequorin, the luminescence of the crystal jelly *Aequorea victoria* (below), was awarded the 2008 Nobel Prize in Chemistry, for the development of its use as a gene marker and other biomedical applications.

BELOW: GABRIEL BOUYS / GETTY IMAGES. TOP RIGHT: 3DSAM79 / GETTY IMAGES

SEA SPARKLE IS ACTUALLY TINY spherical microalgae called *Noctiluca scintillans* – yet another splendid Latin name – *nocti-* meaning night, *-luca* meaning light, and *scintillans* meaning scintillating, glittering, or sparkling. The sparkling night light!

Noctiluca appears as unattractive pink slicks on the water during the day. Next time you see these slicks, come back at night. Bring a water bottle with a sports cap, so you can control the water flow. After dark, spritz some water on it, to elicit the magnificent blue flash. You may want to jump in and dance in the glow, and that's okay too. It isn't harmful to us.

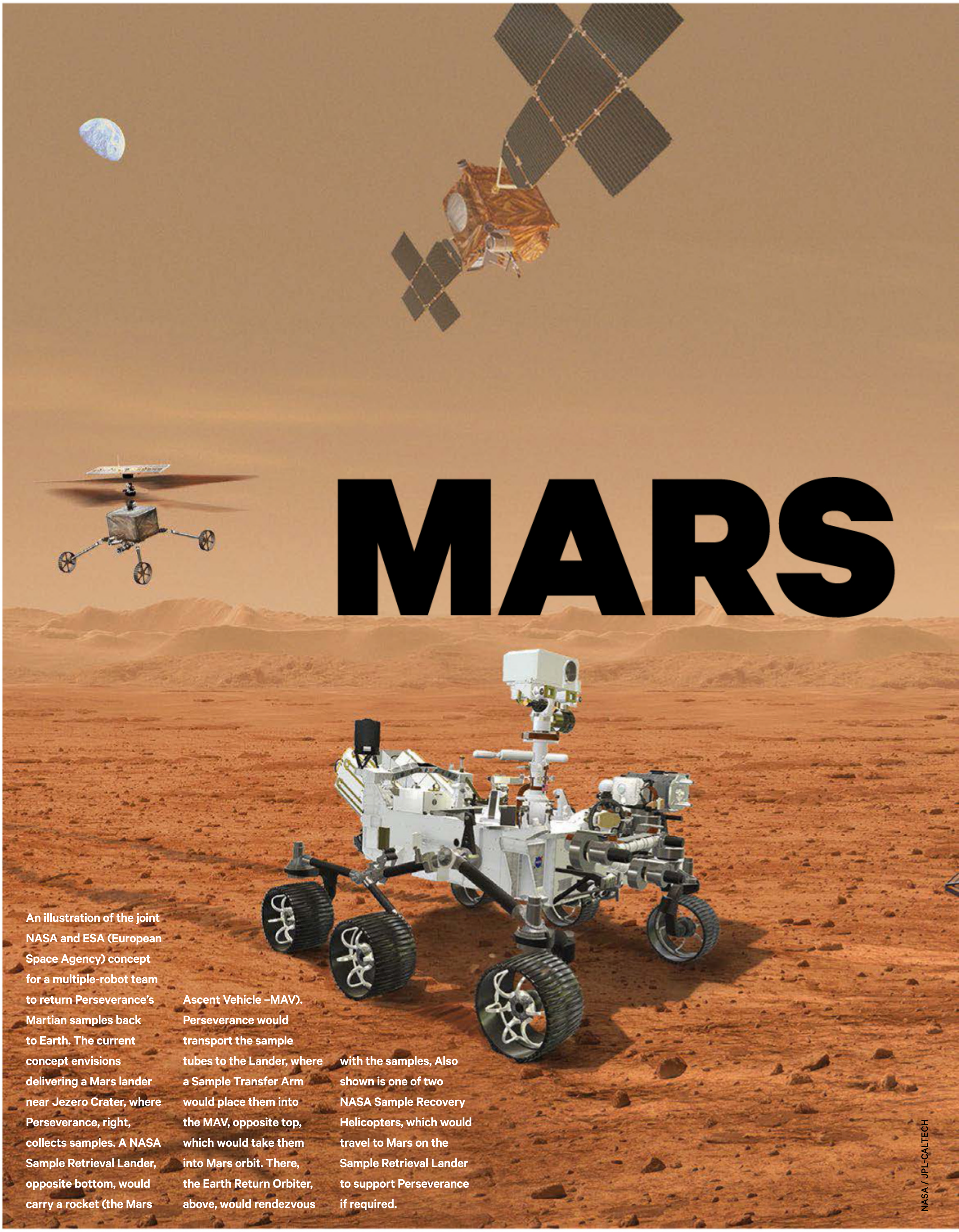
Noctiluca embodies both beauty and beast. Beauty, in the sheer brilliance of its light. Unlike many types of nature's luminescent displays, it's easy to observe *Noctiluca* with the naked eye. And beast, in that *Noctiluca* is an oxygen-sucking, ammonia-exuding, voracious pest.

I'm not being unkind. *Noctiluca* is an unusual type of algae that doesn't photosynthesise, so rather than making oxygen, it obtains it from the water. In bloom concentrations, *Noctiluca* can strip the water of oxygen, leaving heavy breathers like fish and crustaceans gasping. And without photosynthesis, it can't make its own food, so it eats other organisms to survive. Again, in bloom conditions, it can vacuum up all the phytoplankton and even small zooplankton like microcrustaceans, fish eggs, and fish fry. Worse, as it ages it releases ammonia into the water. Often, these blooms result in mass fish deaths.

Nutrient pollution from urban runoff and aquaculture, combined with increasingly warmer waters, mean *Noctiluca* is doing more of what it does best. Don't blame *Noctiluca*, however: it's just responding to the world we're creating.

And remember: if you *are* lucky enough to encounter sea sparkle on the type of low-energy beach where small waves swirl around rocks, its sheer beauty may cause Stendhal Syndrome.

Biologist **LISA-ANN GERSHWIN** has described more than 200 species of jellyfish. This is her first story for *Cosmos*.



MARS

An illustration of the joint NASA and ESA (European Space Agency) concept for a multiple-robot team to return Perseverance's Martian samples back to Earth. The current concept envisions delivering a Mars lander near Jezero Crater, where Perseverance, right, collects samples. A NASA Sample Retrieval Lander, opposite bottom, would carry a rocket (the Mars Ascent Vehicle –MAV). Perseverance would transport the sample tubes to the Lander, where a Sample Transfer Arm would place them into the MAV, opposite top, which would take them into Mars orbit. There, the Earth Return Orbiter, above, would rendezvous with the samples, Also shown is one of two NASA Sample Recovery Helicopters, which would travel to Mars on the Sample Retrieval Lander to support Perseverance if required.

NASA / JPL-CALTECH

Material retrieved from the Moon and asteroids is all very fascinating, writes **RICHARD A LOVETT**, but it's samples from Mars, projected to reach Earth in the early 2030s, that has scientists most excited.

ROCKS:

COMING SOON TO A LABORATORY NEAR YOU

Two years ago, a Japan Aerospace Exploration Agency (JAXA) capsule parachuted to Earth in the desert near Woomera, South Australia. On board were precious grains from the surface of the asteroid Ryugu, whose secrets will be studied for years to come in laboratories around the world.

Of course, it wasn't the first time extraterrestrial material had been brought back to Earth for study. NASA's Apollo program returned a total of 382 kilograms of rocks from six separate Moon landings, and the Soviets also successfully returned lunar soil samples in three less-heralded robotic missions between 1970 and 1976. The Chinese have also entered the act, successfully retrieving 2kg of lunar soil samples in December 2020 – only 10 days after JAXA's asteroid triumph.

But the big prize for scientists salivating to get extraterrestrial samples into their highest-tech lab equipment is Mars.

The Moon is interesting because it was built from pieces blown off the Earth by a giant collision and can tell us much about our own planet's history. Asteroids are interesting because they contain fragments from the early history of the Solar System, from which we can piece together not only the origins of the Earth, but how our planet may have acquired the building blocks of life.

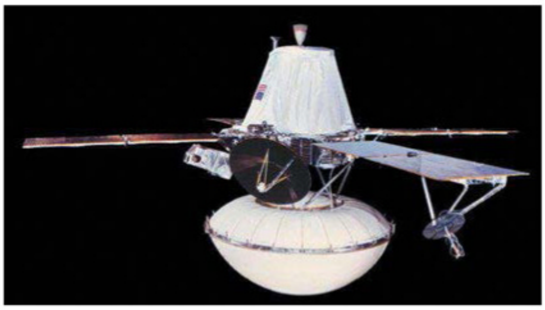
But Mars? Since the 1970s, planetary scientists have known that it had water, with rivers, lakes, and possibly an ocean. At one time it was warm and wet, and even as its lush, early climate faded, it still had parts that may have looked a lot like portions of Iceland, Australia, the Canadian Archipelago, the American Southwest, and Chile's Atacama Desert. And while some of these earthly places are pretty barren, all have life.

If we're looking for signs of one-time life on another planet – at least one we can get to with today's technology – Mars is the place. Not that this means Mars had life. But there is little doubt that it was once habitable.

AUDACIOUS PLANS – AND HOW TO IMPROVE THEM

The search for signs life in the rocks and soils of Mars is nothing new. NASA's two mid-1970s Viking landers were primitive by today's standards, but they still were able to carry chemical labs whose primary goal was to find metabolic traces of life on the Martian surface. (They failed to do so, though the results were not without controversy: see "Viking life test", at right).

Since then, the focus has shifted to hunting for signs of one-time habitable environments, many of which have been found by the last suite of NASA rovers: Spirit and Opportunity (2004–18), Curiosity (2012 to present), and Perseverance (February 2021 to present). But as sophisticated as these rovers have become, they are no match for Earth's labs, which can perform microanalyses impossible to do with even the most sophisticated robotic laboratories.



Best known for his acclaimed public television series *Cosmos*, Carl Sagan (top right) poses with a model of the Viking lander in Death Valley, California, in the 1970s. The Viking spacecraft (above right) flew with its lander encased in a "bioshield".

VIKING LIFE-TEST CONTROVERSY

A primary mission of both of NASA's 1976 Viking landers was to look not just for signs of ancient life on Mars, but signs that the Red Planet might still be inhabited.

To do this, they scooped up soil samples and conducted a number of tests, one of which was to add a C14-labelled nutrient solution to the soils and incubate them.

If Earthlike life was present, the theory was, it would metabolise these nutrients and produce C14-containing gases such as carbon dioxide or methane.

All of the other tests came up negative, including ones looking for organic carbon (from bits and pieces of microorganisms) in the soil samples. But, the "labelled release" experiment – as it was called – did indeed produce positive results.

As a video from the New Mexico Museum of Space History puts it, "evidence for life was seen, but no bodies were found".

Just why isn't clear, although most scientists don't believe that the Viking experiments actually found life. The leading theory is that oxidising chemicals like perchlorates, now known to be contained in Martian soils, could have reacted with the nutrients and released C14-containing gases, without the need for life.

But other scientists disagree, and one of NASA's currently operating rovers, Curiosity, has repeatedly detected anomalous levels of methane, a compound that might (or might not) be a sign that Mars *still* has life, waiting to be more conclusively detected.

COSMOS • A PERSONAL VOYAGE / DRUYAN-SAGAN ASSOCIATES, INC; NASA

ULYANA HORODYSKYJ PENA

The harsh landscape of the Atacama Desert, Chile, has been used for Mars expedition simulations. Covering more than 100,000km^2, the Atacama is the driest non-polar desert in the world.

Now, the dream is nearing reality. Last July, NASA and the European Space Agency (ESA) announced the final phases in an ambitious program to get pristine Martian material samples back to Earth by 2033. And not just one sample, but as many as 33, each from a different site, totalling as much as 4.5–5kg.

Yes, that's a tiny fraction of what Apollo brought back from the Moon, but given the distance, it's a stunning step forward. The program is called Mars Sample Return (MSR) and at its heart is the Perseverance rover and its plucky helicopter Ingenuity.

Getting a sample back from Mars isn't a simple process – it's much more complex than Apollo bringing rocks back from the Moon or JAXA visiting an asteroid. NASA has compared it to a relay team, in which, in the initial concept, six separate vehicles were going to be involved.

The first was Perseverance. Its job was to collect samples, and, like a sea turtle nesting its eggs on a beach, deposit them in a series of caches. Perseverance would be followed by two other landers. One would deploy an ESA-built Sample Fetch Rover designed to chase down Perseverance's trail, retrieve the samples from their caches (and possibly from Perseverance itself, if it was still functional), and bring them back to a second lander. Quick, fast, and efficient: that was the goal.

"The engineer in me was fascinated by [that], because it's designed to travel much faster than previous Mars rovers, probably about four or five times as quickly," says MSR program manager Richard Cook, who's based at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California.

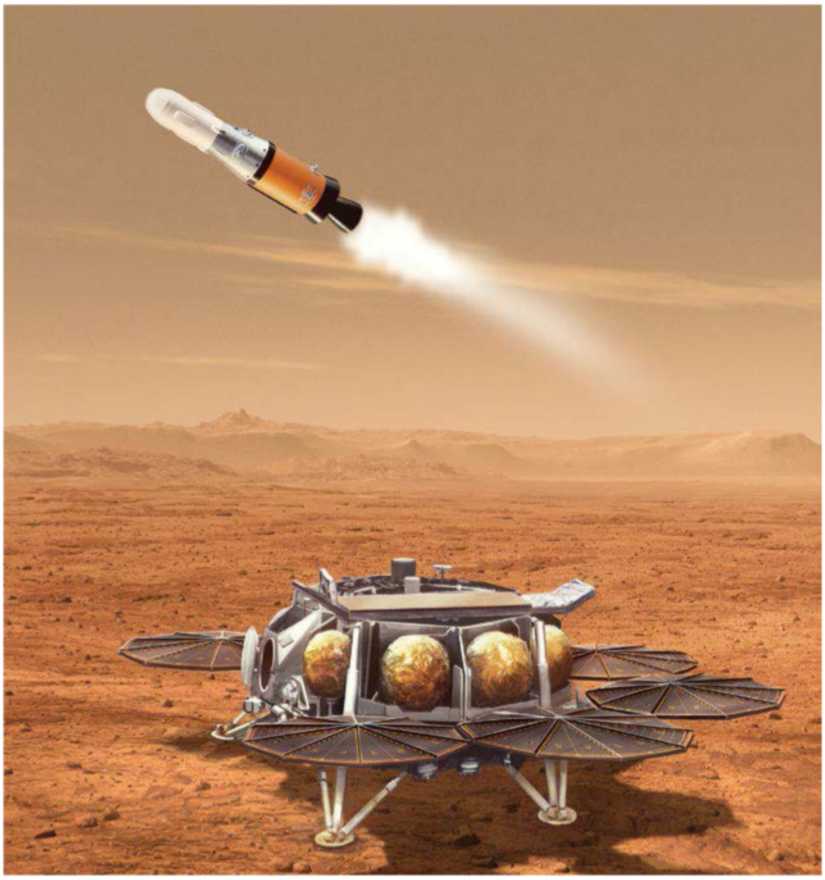
The second lander, called the Sample Retrieval Lander, would carry a rocket called the Mars Ascent Vehicle. The samples would be put in the rocket (which in artists' renderings looks a lot like a torpedo). That rocket would blast off from the lander and rendezvous with a sixth and final vehicle, an ESA-built orbiter that would scoop up the sample package, stow it away, and ease out of orbit for a slow return to Earth.

"Relay team" is indeed a good description, with the samples playing the role of the baton. The plan was also rather complex, with a lot of parts that had to operate flawlessly, millions of kilometres from Earth. Audacious barely begins to describe it.

The current plan is still audacious … but two of the major parts have been eliminated and a new, never-before-dreamed-of backup has been added.

The deleted parts are the Sample Fetch Rover and the lander intended to deploy it. Perseverance has performed so well, NASA scientists said in a 27 July briefing, that there's little fear it will perish before the Sample Retriever Lander arrives in 2028. After all, its cousin, NASA's Curiosity rover, is still going strong more than 10 years on, and NASA's Mars rovers have a good track record for being durable. That means that

The illustration below focuses on a concept for a proposed NASA Mars lander-and-rocket combination that would play a key role in getting Mars samples back to Earth. The machine at bottom, the Sample Retrieval Lander, would carry a small rocket, above, about 3m tall, called the Mars Ascent Vehicle (MAV) to the Martian surface. After loading the rover's sealed sample tubes into the rocket, the lander would launch the MAV into orbit around the Red Planet.



HEROIC HELICOPTER

When it was included on NASA's Perseverance rover as an additional 1.8kg of payload, the mission's tiny Ingenuity helicopter was supposed to be a one-month affair, intended simply to test whether it was possible to fly in the thin air of Mars. But the intrepid helicopter wasn't just a crowd-pleaser for space buffs; it worked wildly beyond expectations. As of midsummer 2022, it had completed 29 flights – 24 more than planned – and proven itself an invaluable companion for the Perseverance rover.

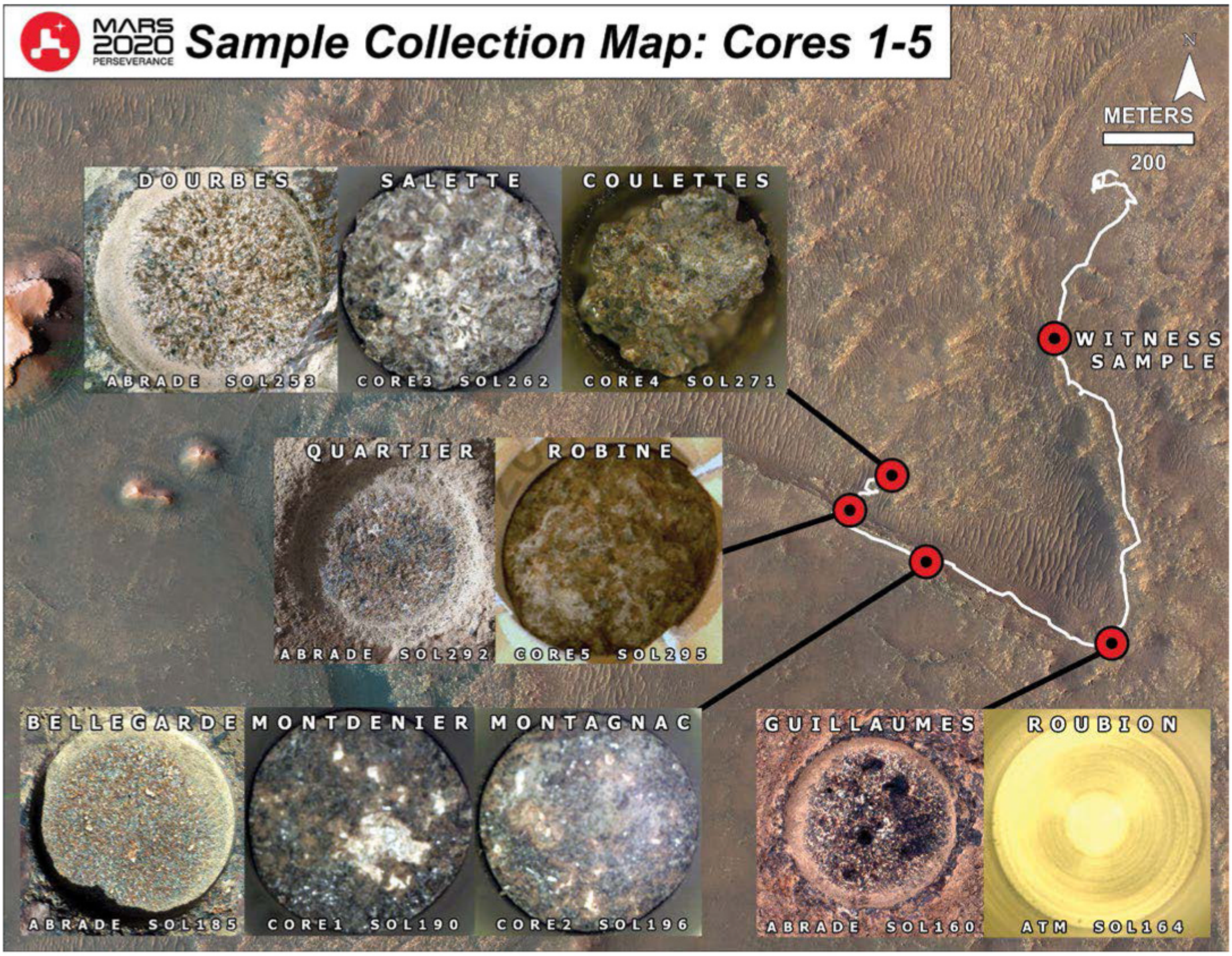
Initially, its biggest limitation had been the combination of its three-minute battery life and the need to find safe landing sites before its battery died. The safest thing to do was to scout no more than 60 or 70 seconds ahead, then return to its prior base to recharge its batteries, while scientists back on Earth looked to see if, in the process, it had found a safe place to land on its next foray. But that's cumbersome, time consuming, and with all of those back-and-forths reduces the helicopter's maximum speed across the terrain by a factor of four.

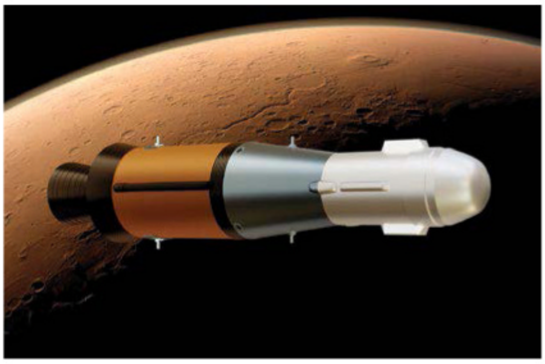
"We quickly figured out that if we had to scout out every site before we landed, we would dramatically restrict operations," Matt Golombek, a planetary geologist at NASA's Jet Propulsion Laboratory, said at the 2022 Lunar and Planetary Science Conference in The Woodlands, Texas. In fact, there were concerns that the helicopter would eventually get outrun by the rover and have to be abandoned.

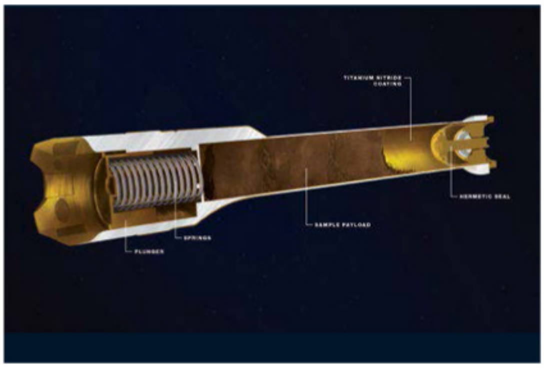
What was needed was to find a way to find safe landing zones from space, so the helicopter could go directly from one to another. And luckily, that was Golombek's specialty – something he'd been doing ever since the Mars Pathfinder landing in 1997.

"My day job is selecting landing sites on Mars," he says. "I've spent most of my career looking for rocks." With 29 helicopter safe landings (and counting), it looks like he knows what he's doing.

NASA / JPL-CALTECH







This annotated map (above) shows the locations where Perseverance collected its first witness tube and filled its first samples. The name that the rover's science and operations teams used to define a rock target on the Martian surface appears at the top of each inset image. Also indicated is the Martian day, or sol, of the rover's mission and whether the image shows a target that has been abraded – by drilling the upper few millimetres of the rock surface – or is one from which a core sample was taken (the anomalous Roubion sample was drilled, but no material collected). All things being equal, these samples and up to 27 others will leave Mars' surface aboard the Mars Ascent Vehicle (left).

NASA / JPL-CALTECH / MSS; NASA X 2

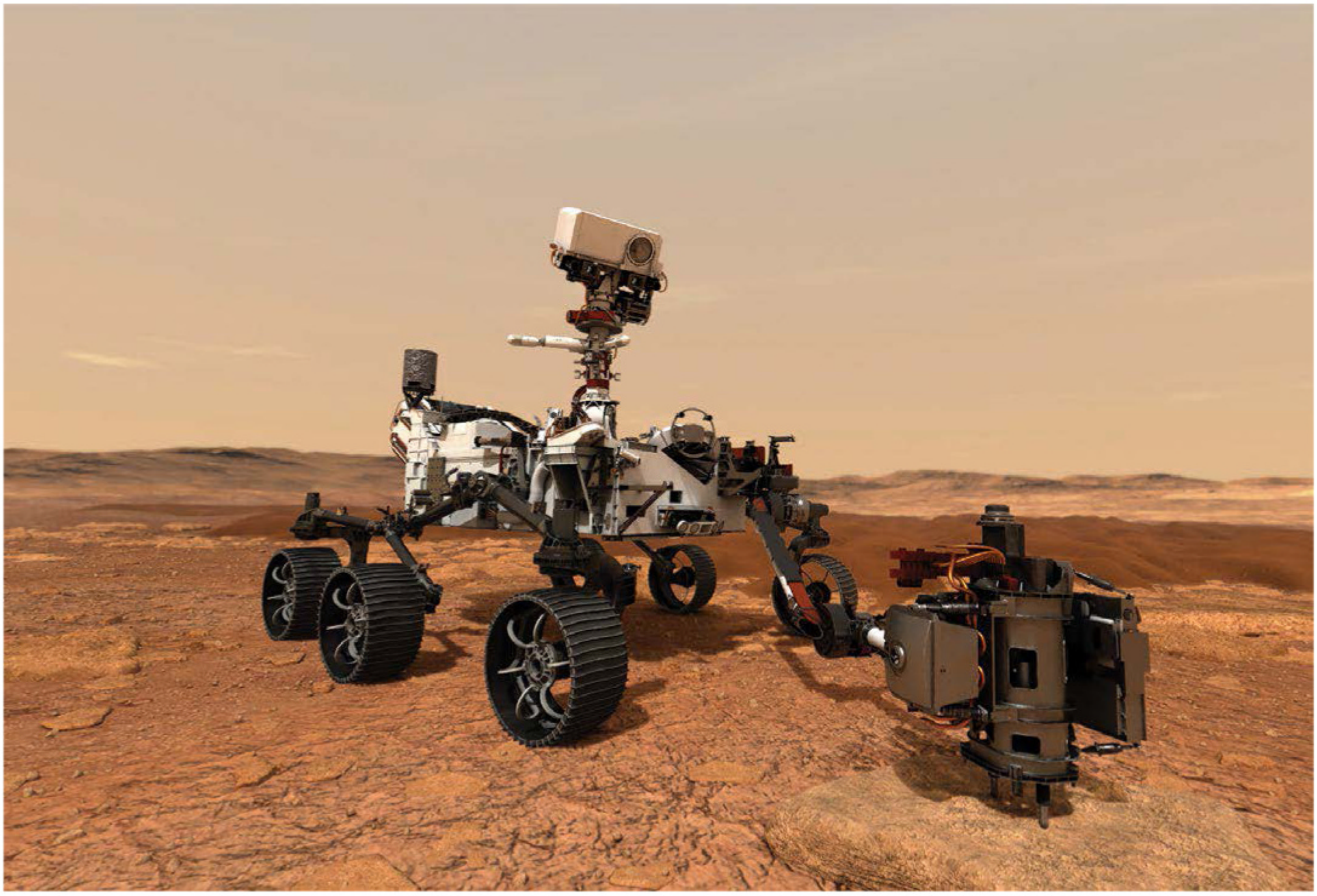
instead of relying on the Fetch Rover (and its lander), NASA will simply aim to land the Sample Return vehicle, with its ascent rocket, as close as possible to Perseverance and let Perseverance roll over to deliver the samples itself.

That's a major improvement in the plan, Michael Meyer, NASA's lead scientist on the project, told *Cosmos*, because however much success recent missions have had, landing on Mars "[is] always a risky proposition".

How close to Perseverance the Sample Retrieval Lander will set down is yet to be determined. "Right now, I think they are considering about 270 metres as the closest distance," Meyer says. Landing closer, is technically possible, but not worth the risk of accidentally coming down on top of Perseverance. Also, he says, "part of the trade [off] is fuel versus landing accuracy. The more pinpoint you want to be, the more fuel you need to carry."

At the same time, landing reasonably close is important, because in addition to the ascent vehicle, the lander will now carry two Ingenuity-class helicopters.

That's because the current helicopter has proven so durable that NASA has decided that similar ones,



equipped with some form of grabbing device, can serve as backup sample-retrievers if Perseverance itself is no longer up to the task. These helicopters, however, have limited range, so it's important not to hedge so far in favour of safety that the lander comes down out of helicopter range from Perseverance. "The goal is a minimal but safe distance," Meyer says.

MEANWHILE, BACK ON MARS...

In the meantime, Perseverance is busily collecting samples. As of 24 August, Meyer says, it had 15 on board, with more soon to come. Many of these samples are duplicates, taken two from a site. The plan is that when the total reaches about 20, one of each pair will be deposited in a cache where, if something disastrous happens to the rover and its onboard collection of

The primary instrument aboard Perseverance (above) for coring rock samples is its go-go gadget-arm drill. A concept model (left) of NASA's orbiting sample container shows how tubes of Martian rock and soil samples will be stored while being returned to Earth; at bottom left sits a model of the sample-holding tube. The sample container will help keep contents at less than 30°C to help preserve the Mars material in its most natural state.

NASA / JPL-CALTECH X 2

PREPARING TO SEARCH FOR LIFE ON MARS... ON EARTH

Before Perseverance set off to collect its precious samples, scientists were honing their techniques on Earth. One place that particularly appealed to them was the driest place on Earth, Chile's Atacama Desert, where the city of Calama went 401 years – from 1570 to 1971 – without a single recorded drop of rain. Except around springs and other water sources, there's not a lot of signs of life on the Atacama's surface – where harsh sunlight and extreme temperatures also mimic those of Mars. "NASA has used this site as an analogue for Mars in order to test instrumentation [and] see what it takes to detect the slightest hints life," says Ulyana Horodyskyj Pena, founder and expedition leader for Science in the Wild, a citizen science group based in Boulder, Colorado.

Also useful, Horodyskyj Pena says, is to study rocks on Earth comparable in age to those Perseverance is exploring on Mars. Particularly important are those in the Pilbara region of Western Australia (Read more about NASA's visit there in *Cosmos* 86). At 3.5 billion years old, they are only 300 million years younger than those in Jezero Crater. They also have similar mineralogy to Jezero rocks and preserve ancient structures known as stromatolites, which appear to have been created by large mats of bacteria that grew into pillars a metre or so high.

samples, the backup cache can still be retrieved by the Sample Retrieval Lander and its twin helicopters. (If the rover operates as expected, the duplicates in the cache will be not be retrieved.)

Already, though, scientists are learning a lot about the rocks they are collecting. One big surprise has been the discovery that even though Perseverance's landing site in 45-kilometre-wide Jezero Crater is known to have once contained a large lake, the rocks in its vicinity weren't composed of the lakebed sediments. Instead, they are volcanic rock that must have been there as bedrock before the water arrived.

That's an exciting find, scientists say, because volcanic rocks are known to be excellent timekeepers, containing crystals whose levels of certain trace isotopes reveals the precise moment when they formed. That means that these crystals provide a very precise date for the formation of the lakebed, and by extension an important constraint on when in the planet's history the lake existed. (It has to be younger than the volcanic rocks beneath it.)

"This will address some major questions," says the rover's project scientist Ken Farley, of California Institute of Technology (Caltech). "When was Mars's climate conducive to lakes and rivers on the planet's surface, and when did it change to the very cold and dry conditions we see today?"

Also valuable is the fact that by happenstance, Perseverance came down right near the boundary of two distinct volcanic formations, now named the Máaz and Séítah.

The Máaz formation (whose name means "Mars" in the Navajo Native American language) appears to be the younger of the two, Vivian Sun, a planetary scientist and systems engineer at JPL said earlier this year at the annual Lunar and Planetary Sciences Meeting in The Woodlands, Texas.

Séítah appears to be a bit older (though how much older won't be known until samples are returned to Earth). Its name means "amidst the sand" in the Navajo language – an apt description of why NASA flight engineers had marked this region on landing maps with the equivalent of a skull-and-crossbones.

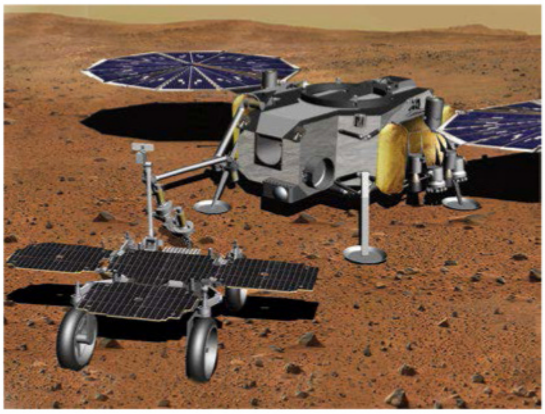
Getting samples from Máaz was easy. It was the area in which Perseverance landed, chosen because it is firm, flat, and largely free of dangerous boulders. Getting samples from Séítah was harder, because the region really is full of potentially fatal sand traps. That's where the Ingenuity helicopter proved its worth, not only helping Perseverance locate suitable rocks for study, but assisting it in plotting an approach to them and then a safe retreat. But getting multiple samples from each formation, along with other geological evidence about their settings was worth the effort.

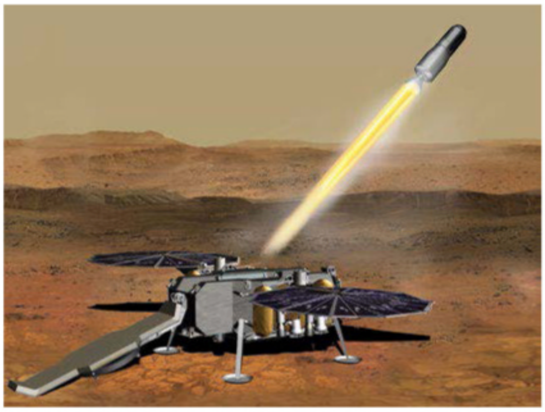
"Even before landing, our science team realised that understanding the crater floor is a very high priority," Sun says. "The goal is to piece together the overall story of how the lake in Jezero Crater formed – putting together the ancient history of what happened at Jezero Crater."

With that part of its mission completed, Perseverance is now on its way to climbing out of the crater floor, beginning by exploring rock formations along the slopes of a giant delta, formed when a billions-of-years-ago river spilled from the highlands, through the crater rim, and into the lake.

Now high and dry, the delta marks the spot where flowing water hit the lake, slowed, and dropped its sediments in what is now a steep bluff about 45m tall. Already Perseverance is collecting rock samples from around its base – rocks that may even preserve ancient signs of life, if life once flourished in the shallow waters near the delta.

And from there? Who knows what treasures Perseverance will find as it climbs through the delta, then up the ancient river channel toward the highlands beyond. After all, it still has at least 25 remaining sample tubes, and six years to find the best places to fill them before the Sample Retrieval Lander comes to complete its mission. With that kind of timeline, Perseverance has plenty of opportunity to live up to its name. ◉





Two of the many moving parts (above right) in the first Mars retrieval plan have as of mid-2022 been deleted. The Sample Fetch Rover, at left, and the lander intended to deploy it aren't necessary, say NASA scientists, because Perseverance has performed so well that there's little fear it will perish before the Sample Retriever Lander arrives in 2028. Deleted parts notwithstanding, it will still be an outstanding feat for NASA and ESA to successfully get the samples off Mars (below right) and successfully back to the Earth.

NASA / JPL-CALTECH X 2

RICHARD A LOVETT is based in Portland, Oregon. His previous story, on DART's mission, appeared in Issue 94.

The medical WHAT-IF that could change clinical trials forever

The 2009 emergence of H1N1 led a few medical professionals to realise how unprepared they were. An informal group including an ICU doctor, care clinicians and a statistician met irregularly for more than a decade to create a thought experiment – a groundbreaking system that could quickly gather and analyse data and offer treatment suggestions for an unknown pandemic pathogen. As **TANIA EWING** reports, their timing was impeccable.

Before 2009, the town of La Gloria, about 200 kilometres east of Mexico City in Veracruz province, Mexico, was little known and generally unremarkable. Perched amid mountain peaks at 2460 metres elevation, the town of about 2200 residents is a major pig-farming centre: the Granjas Carroll de Mexico farm about 8km from La Gloria raised nearly 1 million pigs in 2008.

In 2009 a new strain of the H1N1 influenza emerged. Within weeks, swine flu (as it became known) was spread by international travellers, eventually affecting 74 countries and, according to the World Health Organization, killing as many as 575,000 people. Swine flu's zoonotic origins have never been confirmed, but La Gloria was in the frame early as a likely starting place because one of the earliest cases – in a five-year-old boy named Édgar Hernández – was traced there. (Much later, in 2016, a research team from the Mount Sinai School of Medicine, US, declared that the virus likely came from pigs in a very small region of central Mexico, but didn't name La Gloria.)

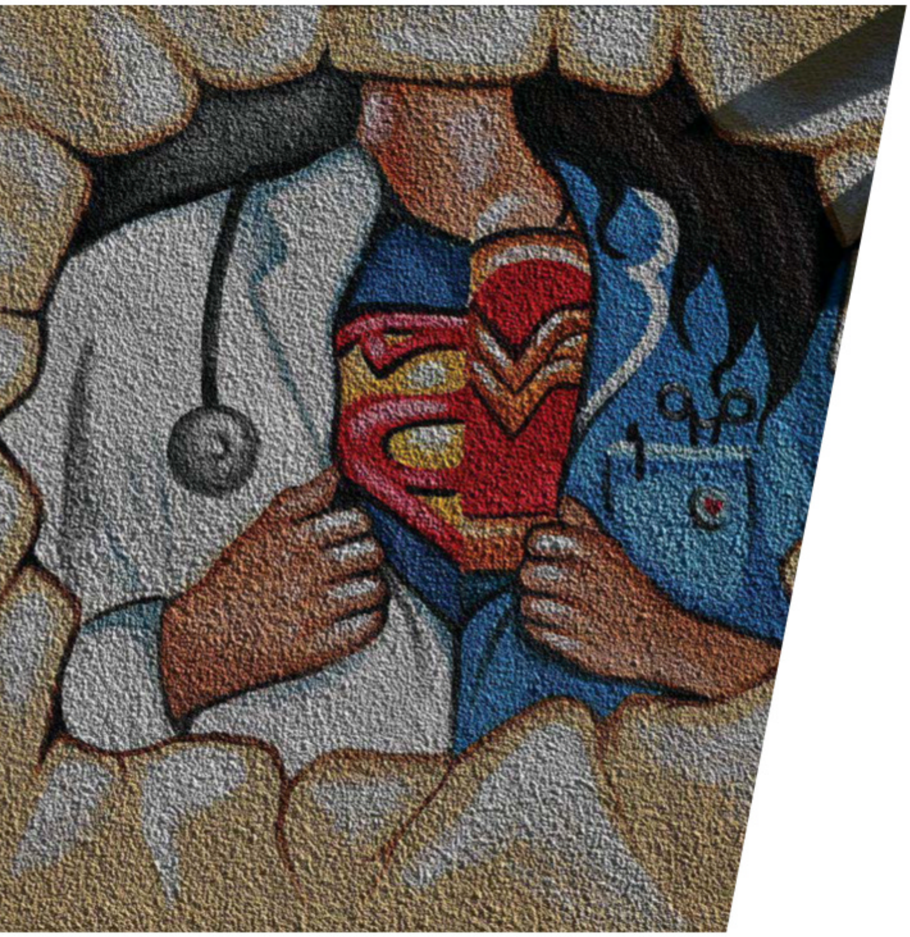
Professor Steve Webb, an intensive care doctor at Royal Perth Hospital, remembers the winter of 2009 as one where "we were flooded with swine flu". In the hospital's 24-bed intensive care units (ICUs), up to half the beds were filled with people infected with H1N1 and on ventilators.

"I remember thinking 'We need to be better prepared for this sort of thing'," Webb says. He and a group of international colleagues wrote a paper that was published in the *New England Journal of Medicine* (NEJM) on the swine flu pandemic. While the paper largely described the cases, the severity of the disease and its impact on ICUs, "it didn't – and couldn't – detail what treatments had worked for which patients. In ICU we just threw whatever we could at patients to keep them alive."

Webb started wondering about ways in which the next pandemic could provide better and timely information to clinicians about which treatments worked, and which did not. By definition, a pandemic has thousands, if not hundreds of thousands, of cases – so getting the numbers wouldn't be a problem. How could they collect and use that data better?

Mural by urban artist Applez, in Mexico City.

PEDRO PARDO / GETTY IMAGES



Unknown artist's work in Pontefract, northern England.

Webb – then and now also Professor of Critical Care Research at Monash University in Melbourne – and a group of intensive care clinician researchers including Derek Angus, Chair of Critical Care at the University of Pittsburgh Medical Center, and Roger Lewis, an emergency doctor and statistician in Los Angeles, started to meet around once a year to work out what could be learnt from what went wrong in 2009. They all had big day jobs; the pandemic thinking was just a side hustle. They'd squeeze their catchups onto the back of international meetings, connected by a certainty there would be another pandemic that would likely be a respiratory disease, and a drive to minimise a new infection's potential devastation.

The only unknowable was when the next pandemic would arrive.

Steve Webb
Professor of Critical Care Research, Monash University

Standard clinical trials are "equivalent to building an arena for a football game and then knocking it down and rebuilding it again for the next game. In a pandemic we knew we wouldn't have that luxury of time"

Flipping the clinical trial paradigm

The WHO has identified influenza pandemics as one of the top 10 threats to global health. In an influenza pandemic, such as swine flu, most people are admitted to ICUs with what is called Community-Acquired Pneumonia (CAP). CAP is the most common form of pneumonia; its causes are bacteria or bacteria-like organisms, fungi or viruses, such as swine flu.

In the years following the swine flu pandemic, Webb and his colleagues focused on developing a new type of clinical trial. Standard clinical trials are laborious in their genesis, often taking up to a year to begin: funding and ethics approval must be obtained and protocols developed before patients are even recruited.

"What we needed was a clinical trial that could be up and running within a couple of weeks after a pandemic hit," Webb says.

But how could they streamline the clunky, bureaucracy-laden, decades-old clinical trial process into one that could adapt to whatever a pandemic would bring, while retaining statistical rigour and patient safety?

In 2010, father-and-son team Drs Don and Scott Berry – experts in clinical trial statistics based in Texas – had designed the I-SPY2 trial, aimed at testing new drugs in high-risk breast cancer patients. It was a novel approach to bring multiple interventions into a large single trial. Its secret lay in Bayesian statistics, which involves the continual reassessment of competing hypotheses in the presence of new evidence. In essence, Bayesian statistics allows the trial design to shift and adapt as knowledge is gained. According to Scott Berry, traditional clinical trials are based around "one question and once that question is answered, then the whole trial is dismantled. And the whole process is rebuilt from scratch to answer the next question," he says, speaking from his home in Austin, the Texas state capital.

"It's equivalent to building an arena for a football game and then knocking it down and rebuilding it again for the next game. In a pandemic we knew we wouldn't have that luxury of time."

To the Berrys, broadening the scope of their Bayesian-based platform trial to a global pandemic made sense. By the time the Berrys joined Webb and colleagues in 2010, the still small group had swelled with members from Europe, Australia, the US, New Zealand and Canada. They continued to convene when they could, still sneaking in meetings after symposiums and sessions at critical care meetings and conferences they were already slotted, and funded, to attend.

The group's emphasis was on developing a platform trial and a network of ICUs that was like the I-SPY2 trial, but with global reach and system-ready when a pandemic hit. A global ambition, but for the clinicians and statisticians who were working on it together, it remained a side hustle.

OLI SCARFF / GETTY IMAGES

TRADITIONAL CLINICAL TRIAL

A traditional clinical trial is a very expensive and time-consuming process, taking many years and substantial resources to progress from phase I to IV. Many trials won't go the distance – they'll be terminated at the end of a phase.

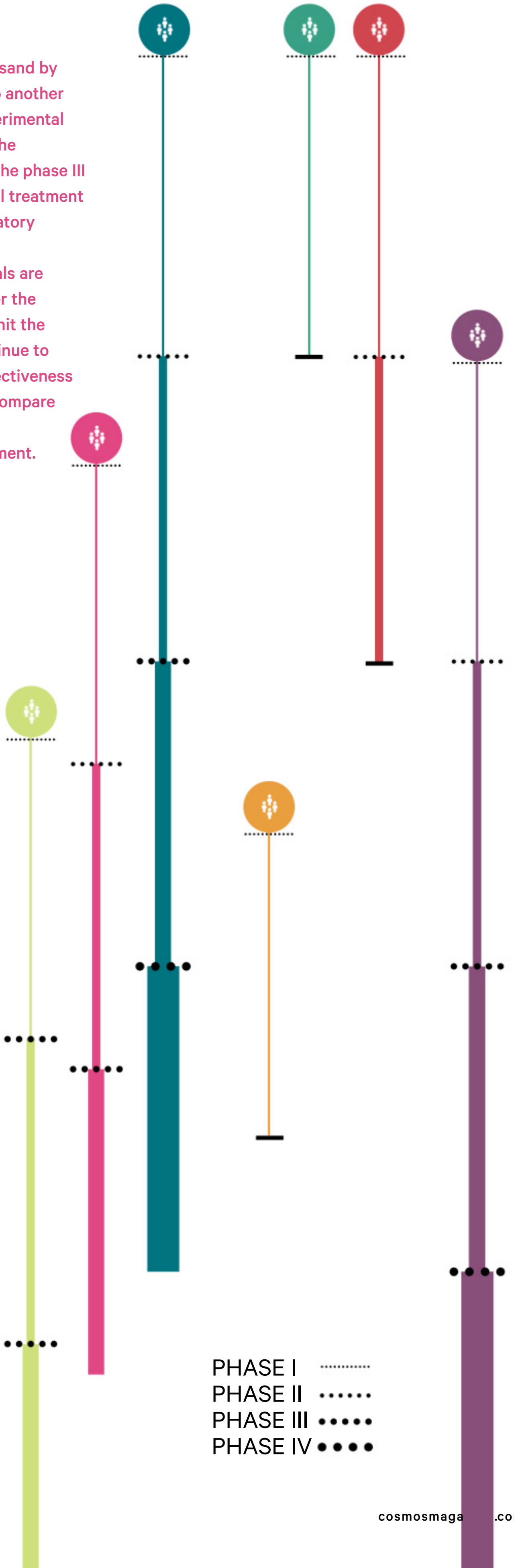
In each trial phase, participants are randomised in equal proportion to different treatments and the trial finishes when a specified sample size is reached. Researchers then examine the data and determine the next action – typically, to continue to the next phase or to stop the trial.

Phase I is a safety study comprising a small number of people (typically 6–80) and run over months to determine a safe dosage range and identify side effects.

In **Phase II**, a cohort of up to several hundred is typically split into two groups, with one group receiving a placebo. The phase aims to evaluate a drug's potential efficacy and to continue gathering information on its side-effects.

Phase III trials study a drug's efficacy in groups from several hundred to several thousand by comparing it to another current or experimental treatment. At the completion of the phase III trial, a potential treatment can seek regulatory approval.

Phase IV trials are conducted after the treatment has hit the market to continue to monitor its effectiveness and, often, to compare it to an already available treatment.



Then, in 2014, the Platform for European Preparedness Against (Re)-Emerging Pandemics was looking for consortia focusing on pandemic preparedness, and offering significant funding for everything from laboratory work to community engagement and surveillance. The group put in a bid and were funded to the tune of $6 million, with Steve Webb the only non-European principal investigator.

The REMAP-CAP trial (Randomised, Embedded, Multifactorial, Adaptive Platform for Community Acquired Pneumonia) was born.

A year later Australia's medical research funding body, the National Health and Medical Research Council, provided an additional $4.4 million funding. The Canadian Institutes of Health Research and the Health Research Council of New Zealand followed, largely through the efforts of the other co-lead of REMAP-CAP, Colin McArthur, Director of Research at Auckland City Hospital.

"By 2017 we had core funding for the program," Webb says. "So, we started to build what would become the world's most complicated clinical trial."

It took a long time for the group to write the protocol for REMAP-CAP. The team had to work out how to collect data and evaluate the eligibility of patients in both quick and easy ways.

"Staff in ICUs are already stretched – we didn't want them to be burdened further by making the process of registering a patient into a REMAP-CAP trial too difficult," Webb says. "We wanted to keep the process to between five and seven minutes, which is no more than an ordinary clinical trial."

GREG BARTON

> “People were coming into ICUs in severe respiratory distress, and we neither knew what was causing it, beyond a form of flu, and more importantly we didn’t know how to treat it”

By 2019 more than 50 hospitals in more than a dozen countries were participating in REMAP-CAP, looking at treatments – antivirals and antibiotics – in Australia, New Zealand, Canada and Europe on people in ICU with community-acquired pneumonia. There had been some moments of concern that a pandemic had already arrived: 2012 saw the MERS virus outbreak, and then in 2015, Zika. Despite initial alarm, neither became global threats.

REMAP-CAP had reached what Scott Berry calls “sleeping mode”: recruiting CAP patients, still working out operational issues but effectively ready to go.

Or so they thought. In December 2019 came reports of a new respiratory disease in Wuhan, China. “But we still thought it was more likely to be another MERS or Zika,” Scott Berry recalls.

By January 2020 reports were escalating that the virus was spreading rapidly and causing high morbidity. “It started to be a real thing then, a real risk that this was the pandemic we had expected” Berry says. “We still weren’t sure, but we shifted staff and thought, let’s get ready.”

In London on 17 January 2020, Steve Webb received an email from Antwerp University’s Professor Herman Goossens, the coordinator of PREPARE, the EU organisation that was the first to provide funding for REMAP-CAP. “He said that his contacts had warned him of a person-to-person transmission of a pneumonia-causing virus in Wuhan in China, which meant this could be the ‘big one’,” Webb recalls.

The REMAP-CAP team started flipping the small number of global sites they already had gathering CAP data into getting ready for what they feared would be an influx of people, “even though at that stage we weren’t sure that the disease would spread outside of China or even outside of Wuhan”, Webb says.

The confusion surrounding the H1N1 pandemic occurred because of the sudden influx of people with CAP into ICUs in the early days of the pandemic. “People were coming into ICUs in severe respiratory distress, and we neither knew what was causing it, beyond a form of flu, and more importantly we didn’t know how to treat it,” he recalls.

Because REMAP-CAP sites globally were already evaluating the use of corticosteroids on bacterial pneumonia, the team woke up the sleeping pandemic stratification in the protocol for the Wuhan disease, as it was then known.

REMAP-CAP recruited its first COVID patient on 10 March, the day before the WHO declared the SARS-Cov-2 virus a pandemic.

Scott Berry
President & Senior
Statistical Scientist,
Berry Consultants LLC

The pandemic no one wanted (but had been planning for)

By definition, pandemics are unpredictable and emerge suddenly. So REMAP-CAP’s premise – to have a protocol and infrastructure in place in order to generate critical evidence, efficiently, about optimal treatment so that clinicians and policy makers can utilise that information to improve patient outcomes – seems challenging, to say the least.

Traditional clinical trials just don’t work in a pandemic. Conventional trials are a fixed design, comparing treatment A with treatment B, with no capacity to change the treatments or sample size or even analyse the results until recruitment is complete. The static and rigid design of these trials simply didn’t meet the needs of a global disease that would be filling hospital ICUs. The REMAP-CAP team had learnt this back in 2010 and 2014.

At the beginning of the COVID-19 pandemic, numerous potential treatments emerged to assist those who were the sickest. Suggestions ranged from the head-lice treatment ivermectin, to bleach, steroids,and to plasma from those who had recovered. Some of these things may have proved helpful, others may have been harmful – but until and unless these treatments were randomised, it would just be guesswork. Regardless of the number of doctors and healthcare workers observing improvements due to one treatment over another, without randomisation these observations would remain anecdotal – an unreliable way to guide treatment.

ADAPTIVE TRIAL

In an adaptive trial, continual data analysis allows researchers to assess the efficacy and safety of multiple treatments in real time. Unlike a standard clinical trial, participants can continue to join the study, and data analysis will randomise them towards more beneficial treatments. Adaptive trials improve health outcomes for participants, avoid ambiguous results, and can end when sufficient data have accrued rather than when a pre-specified sample size is met.

The example at left takes the same trials as on the previous page. Patients are progressively randomised into three initial treatments. Data is collected and analysed continuously. As the green is shown not to be beneficial, randomisation proportions are updated and future participants are randomised towards the blue and red treatments.

Research continues. New treatments are added for trial (purple and pink). More data results in more knowledge: less beneficial treatments dwindle as randomisation proportions are updated.

Lime green is an example of an innovation on the pink treatment, which is showing benefit. The innovation is a success, and supersedes the pink, which although successful has less efficacy than the subsequently developed treatment.

As this moment in time ends, beneficial treatments have large numbers of participants without having sacrificed the important safety steps that a clinical trial provides, while less beneficial treatments aren’t required to play out a costly and time-consuming phase.

The United Kingdom was one of the first countries outside of China to be swamped by COVID-19. The REMAP-CAP program was selected as a national priority trial on 1 April by chief medical officers across the UK. Most ICUs took part, enrolling patients who were admitted for treatment in intensive care. The UK's National Health Service (NHS) already had an embedded research arm in its hospital system with paid research coordinators who facilitated the uptake of the REMAP-CAP protocols.

"These research coordinators were taken off the trials they were on – cardiovascular, cancer etc – and suddenly we had an enormous number of patients enrolling into a whole series of investigational treatments, literally just months into the pandemic," Webb says.

A key to the REMAP-CAP program is that once a treatment is looking favourable it's randomised into the treatment of more patients, effectively speeding up the learnings of the clinical trial. Information from patients already participating in the study is used to help guide the treatment of new patients joining the study. Under REMAP-CAP, as a therapy sees positive results a higher proportion of participants receive that treatment, and fewer participants are randomised to those treatments that are performing poorly.

Colin McArthur
Director of Research,
Auckland City Hospital

> "We had become a factory for generating results and, as soon as we had a result that was statistically significant, we would publish, which was always the aim of the project."

REMAP-CAP global project manager Cameron Green joined the team in 2019, shortly before the COVID-19 pandemic, because he was impressed with the novel design of REMAP-CAP and its Bayesian model, "which ensured that any patient enrolled in a trial would have the benefit of the evidence that had already been accrued, when in normal trials that's not the case", he says.

The inclusion criteria for any of the REMAP-CAP trials aimed to be both broad and blunt: an adult admitted to ICU because of the pandemic disease and requiring some form of organ support. Success was a simple measure: the reduction in deaths during the hospital admission and, in survivors, a reduction in the number of days receiving life-sustaining treatments in an ICU.

With more than 150 UK hospitals on board with another 70 hospitals in Australia and New Zealand, more ICU sites joined across Europe and Canada, and in late 2020, Pakistan, India and Nepal. Later participants included Japan, Singapore, South Africa and Malaysia. But only a few hospitals in the US joined REMAP-CAP – constrained by the very high costs of trials in the US and complex regulatory environment. The University of Pittsburgh Medical Center, with its multiple ICUs, recruited many patients while covering its own costs.

Overseeing it all was Cameron Green, based at Monash University, liaising with international trial coordinators, regional coordinators, statisticians and database providers, adding new domains as new treatments needed testing and working on contracts with every ICU that came on board.

"All the time we wanted to make it easy for the ICU staff to enrol patients, so we worked tirelessly to make the process seamless, because without the ICU staff on board we would never have managed," he says.

In Australia the philanthropic Minderoo Foundation boosted funding for REMAP-CAP, "because it revolutionised the global treatment of COVID-19 in critically ill people in an incredibly short timeframe", according to Dr Steve Burnell, who led Minderoo's COVID-19 response.

Webb says that Minderoo's foundational funding, made early in 2020, was pivotal in the platform's rapid expansion and global impact – especially during the pandemic's critical early phases, before vaccines were available and when so many people were dying from COVID-19 infection.

By mid-2020, REMAP-CAP was joined by other large clinical trials looking at COVID-19 therapies and treatments. The UK's Randomised Evaluation of COVID-19 Therapy (RECOVERY) trial was ward-based and instrumental in finding cheap and effective COVID-19 treatments, though its funding ran out in October this year. In March 2020, the WHO undertook Solidarity, a large, simple, international, open-label, randomised trial in patients hospitalised with COVID-19, looking at the efficacy of drugs like Remdesivir. In the US, the National Institutes of Health conducted, and continues to conduct, trials for the treatment of COVID-19.

According to Steve Webb, only the RECOVERY trial – with its platform also evaluating multiple treatments – was similar to REMAP-CAP, but it focused on patients in hospital wards, while REMAP-CAP studied the very ill in ICUs.

"The two trials worked in tandem to give us a hugely important overview into what treatments work for all patients sick enough with COVID that they were hospitalised," he says.

By the end of the COVID-19 pandemic's chaotic first year, a writing team within REMAP-CAP started to publish. In preparation for the massive amounts of meaningful information that needed to be relayed to clinicians, the team had developed a template that could be completed quickly, with data, methods and discussions and rapidly sent off to major journals like the *Journal of the American Medical Association* (*JAMA*) and *NEJM*.

Along the way, the REMAP-CAP platform utilised information from other trials to adapt what they would study. In June 2020, REMAP-CAP stopped collecting data that evaluated corticosteroids and hydroxychloroquine; the study's first results, published in September, provided confirmatory evidence on the effectiveness of corticosteroids.

In December 2020 REMAP-CAP released research showing that the interleukin-6 inhibitors, tocilizumab and sarilumab, were an effective treatment, including in patients who had been receiving corticosteroids. This result was communicated to the clinical community through an announcement by the then UK Prime Minister, Boris Johnson.

Two days before Christmas 2020, REMAP-CAP sent out an alert that they had paused the use of blood thinners for critically ill COVID-19 patients. Three clinical trial platforms worked together to combine their data on blood thinners, to learn more efficiently that COVID-19 patients in ICU did not benefit from, and were possibly harmed by, anticoagulation drugs.

In February 2022, a landmark paper published in *NEJM* revealed, via REMAP-CAP data, that the use of tocilizumab and sarilumab in COVID patients in ICU led to an 8% reduction in mortality. By this stage, REMAP-CAP had 10 full-time statisticians undertaking analyses that were packaged rapidly for publication in medical journals.

"We had become a factory for generating results and, as soon as we had a result that was statistically significant, we would publish, which was always the aim of the project," Webb recalls.

At its height, REMAP-CAP was running at 360 ICU sites. Since the beginning of the pandemic, the REMAP-CAP team have published eight papers on the treatment effect of 11 different treatments, and have randomised 11,700+ patients. Another three papers covering four treatments are currently being prepared.

What's the next pandemic going to be?

As COVID-19 deaths remain high globally but the world seems to be living with the virus, REMAP-CAP is now transitioning away from the pandemic – although they continue to recruit COVID-19 patients to study new or repurposed treatments as they are developed.

Instead, given the rise of non-COVID respiratory illnesses and pneumonia globally – particularly as the Northern Hemisphere heads into what's predicted to be a harsh and wet winter – REMAP-CAP is continuing to study community-acquired pneumonia.

According to Webb, the REMAP-CAP program is heading back to "sleeping mode" – but with a caveat. Over the past 300 years there has been an influenza pandemic on average every 23 years; swine flu in 2009 was the most recent one.

Street art by Kai 'Uzey' Wohlgemuth in Hamm, western Germany. The text reads: For the real heroes.

Cameron Green
Global Project Manager for the REMAP-CAP trial

"So we are due another pandemic in the next 10 to 20 [years]," Webb predicts.

While COVID wasn't an influenza strain, its impact on the respiratory system was profound, which made REMAP-CAP so relevant. Historically, the pandemics that kill the most people are respiratory pandemics, so efforts like RECOVERY, with its funding cut and trial disbanded in October 2022, and REMAP-CAP – still funded by the EU, New Zealand, Australian and Canadian governments – are not planning on being "retired".

Scott Berry says that COVID has forever changed the way we deal with disease. "Those lessons and these platforms will be used in the next pandemics, our understanding of what pandemic preparedness means has changed," he says.

"We need to continue the urgency for the treatment of non-pandemic diseases that we showed during the pandemic. We have to always be ready to go, we have to be able to pull the rip cord on these trials immediately."

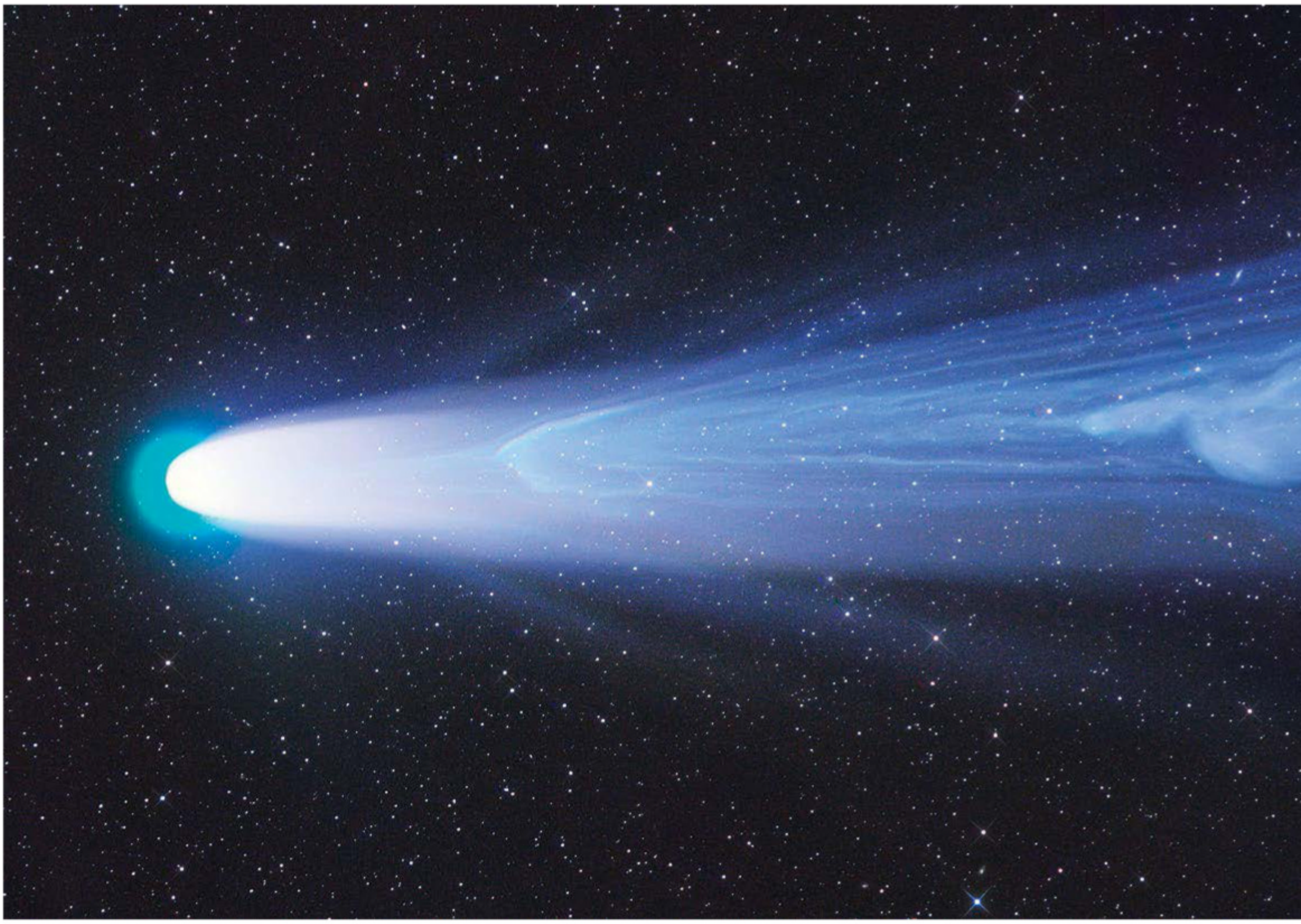
Whatever comes next, "REMAP-CAP is ready".

TANIA EWING is based in Melbourne. This is her first story for *Cosmos*.

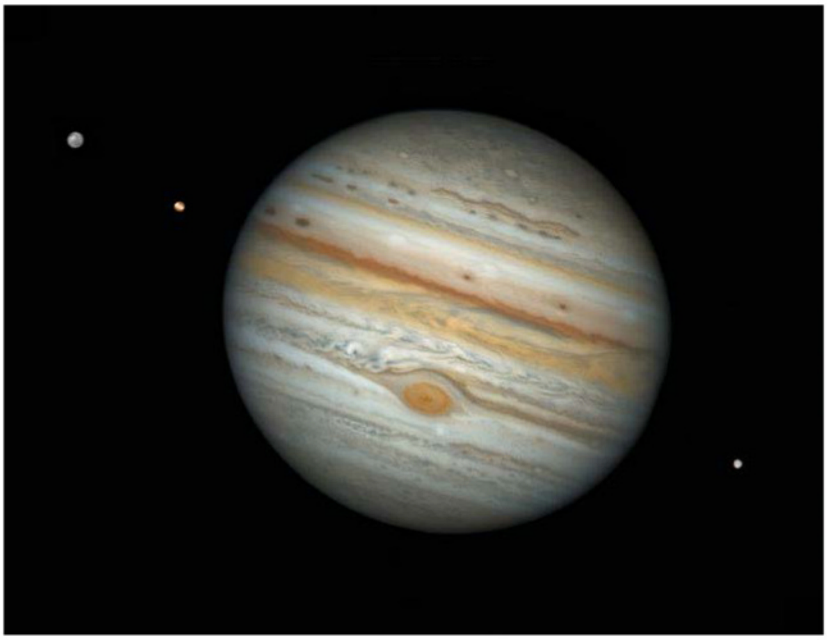
Star struck

Run by the Royal Observatory Greenwich, the Astronomy Photographer of the Year showcases the best of space. This year, the 14th competition received over 3,000 stellar entries from 67countries around the world.

For more information, visit **rmg.co.uk/astrophoto**

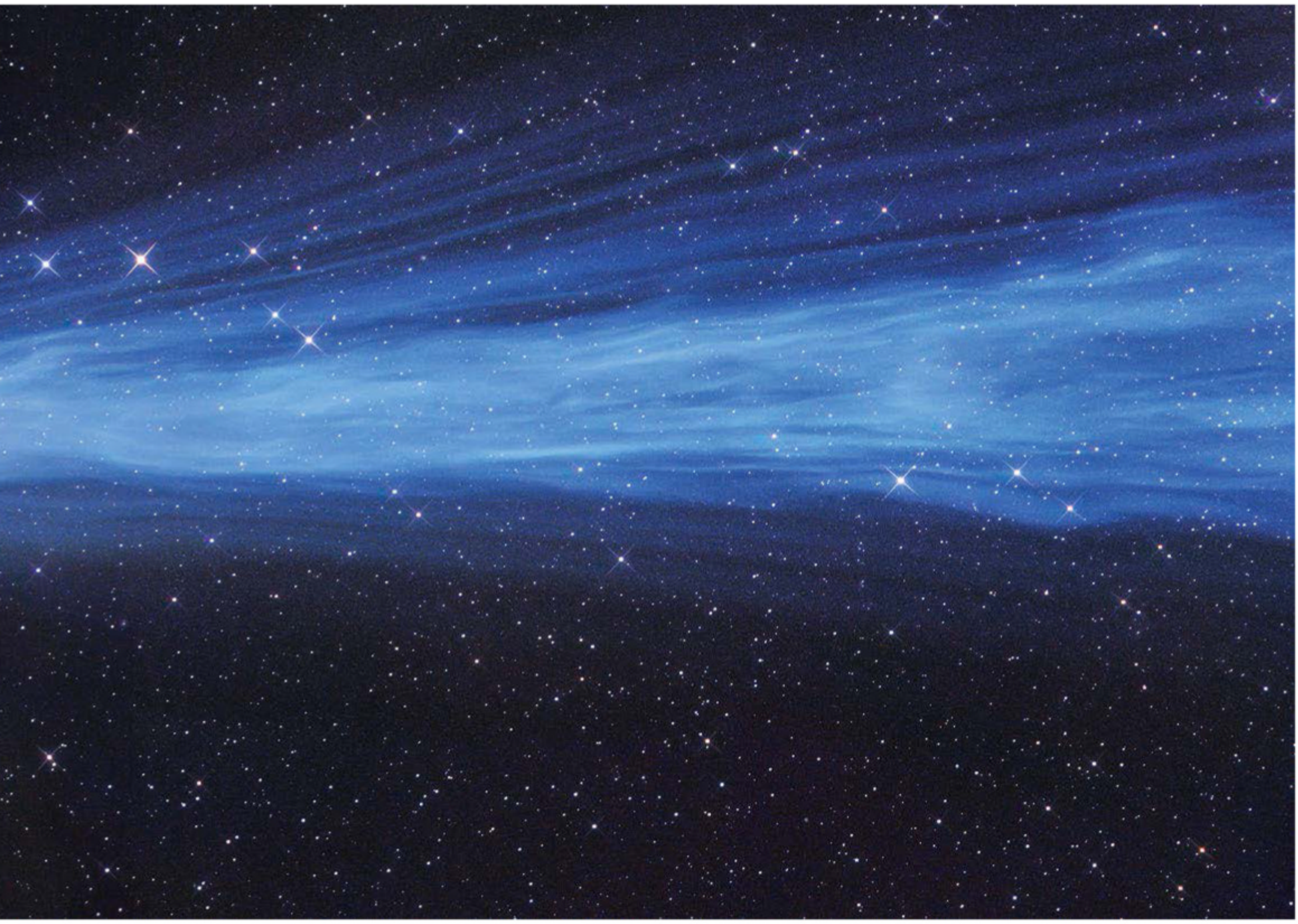


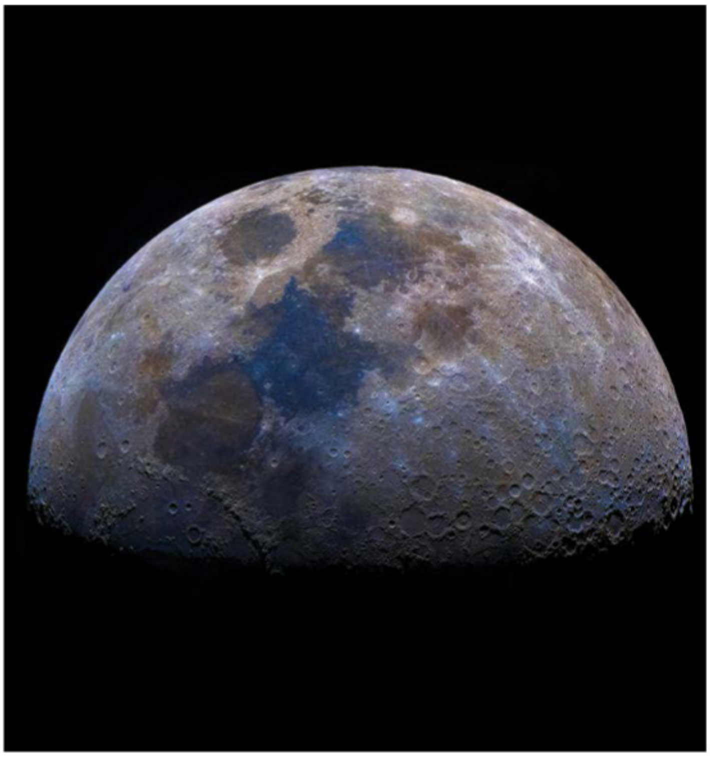
The Jovian family (right): A colourful tribe, Jupiter and three of its largest moons shine from this frame, taken from the El Sauce Observatory, about 200km north of Santiago, Chile, in August 2021. Photographer Damian Peach captured Jupiter's famous Great Red Spot and various storms on the planet's surface; similar details swell from all three of the Jovian moons, including the bright ray crater Osiris, on the moon Ganymede, at top left. *Runner Up – Planets, Comets & Asteroids*



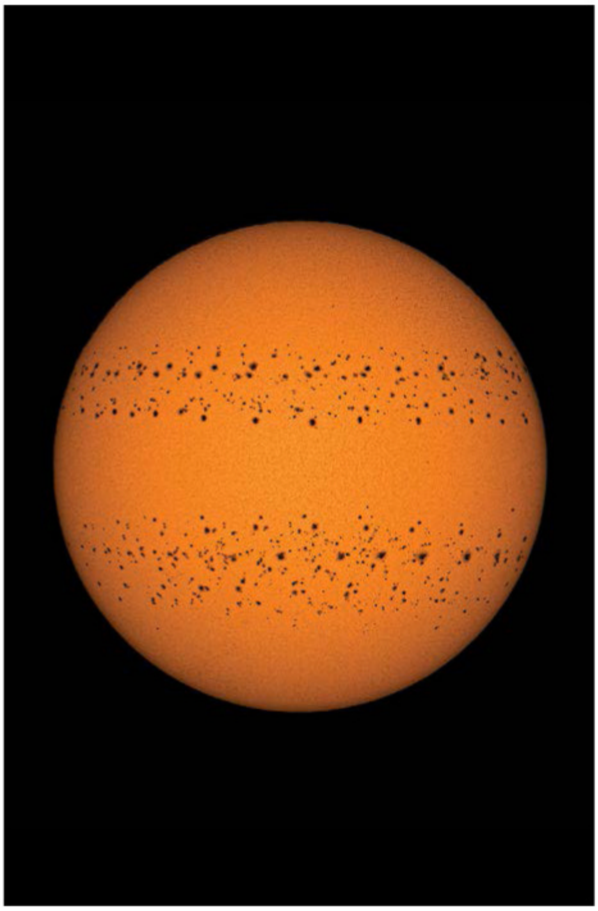
Disconnection event (below): Austrian astrophotographer Gerald Rhemann captured this stunning, comp-winning image from the Tivoli Southern Sky Guest Farm in Khomas, Namibia, on Christmas Day 2021. It reveals the moment a piece of Comet Leonard's tail was pinched off and carried away by solar wind. American astronomer G J Leonard had discovered the comet nearly a year earlier, on 3 January 2021, and it made its closest pass to Earth on 12 December 2021. It's now left the solar system, and won't be seen from Earth again.

Overall Winner, and Winner – Planets, Comets & Asteroids

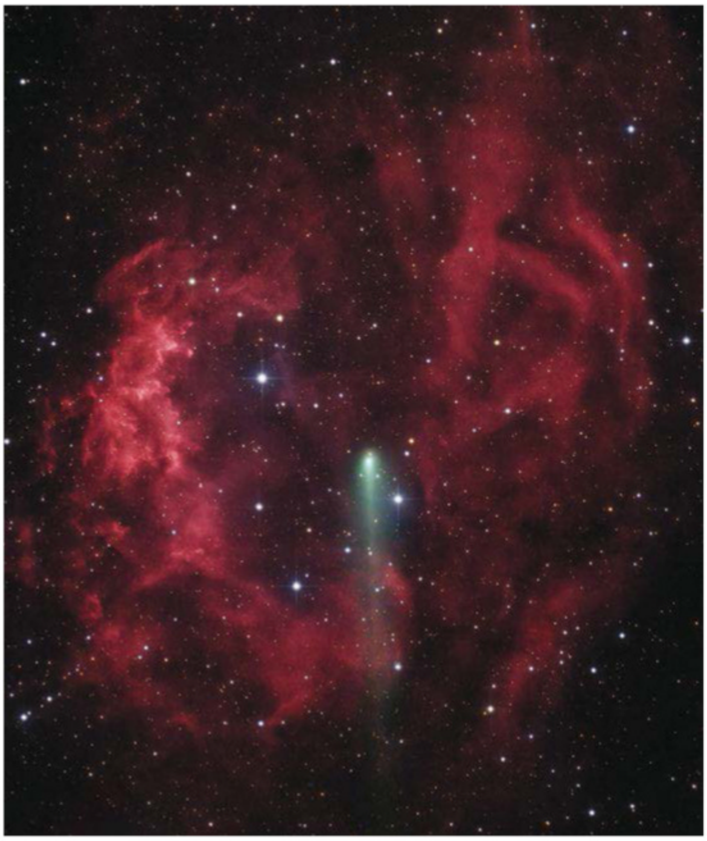




Moon: big mosaic (above): Andrea Vanoni's painstakingly detailed 32-panel composite image of the crescent Moon is a reminder of our natural satellite's proximity to, and intimacy with, Earth. Shot from Lombardy, Italy, in January 2021, the image illuminates the most famous craters, rims, mountains, domes and seas of this lunar phase. *Runner Up – Our Moon*

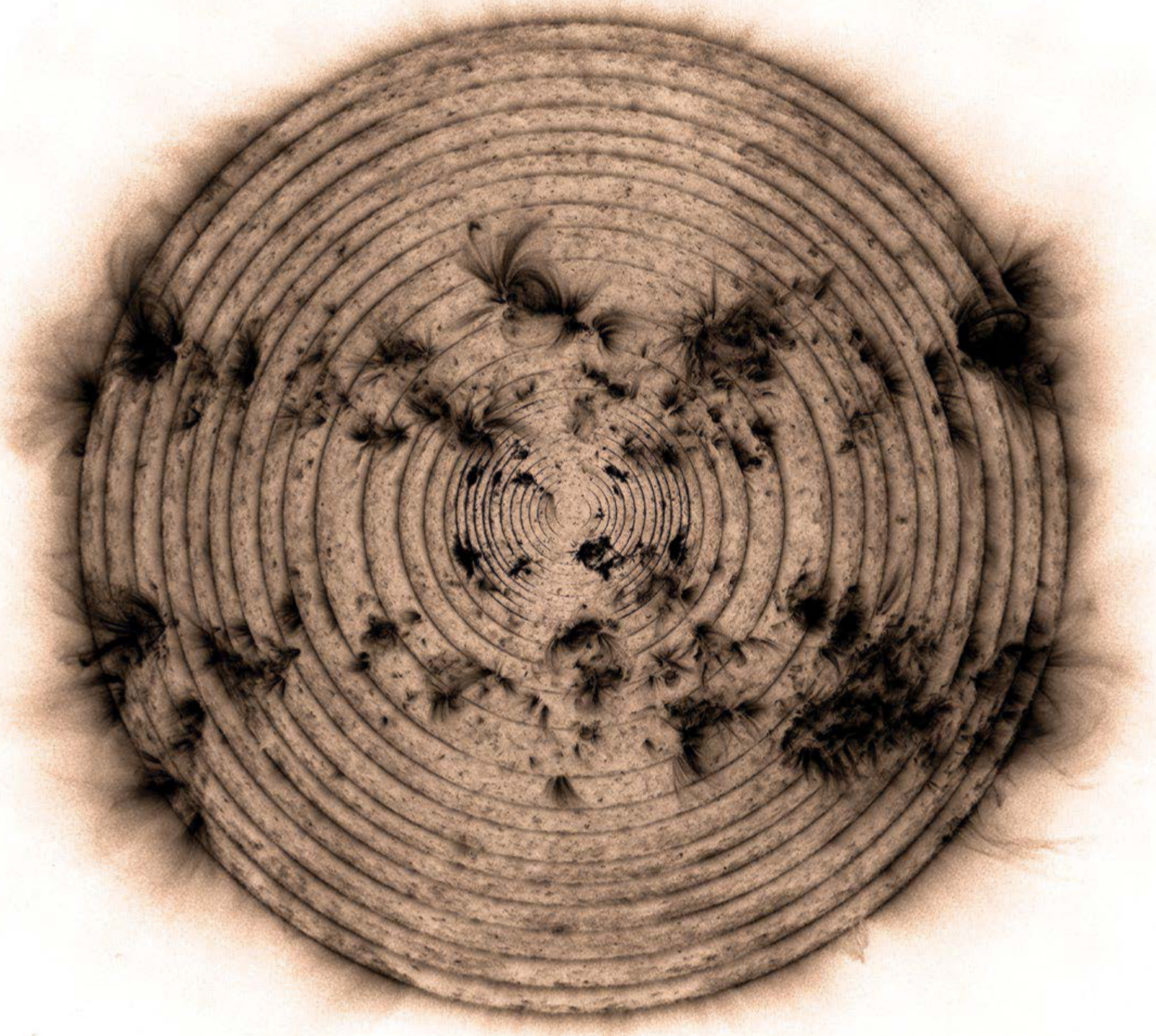


A year in the Sun (above): Soumyadeep Mukherjee captured a frame of the Sun nearly every day between 25 December 2020 and 31 December 2021 (he missed just six days). Then he blended the images, taken from Kolkata, in West Bengal, India, to create a single shot, in which sunspots form two orderly bands on the solar disc, around 15°–35° north and south of the solar equator and gradually start drifting towards it. The image illustrates a phenomenon known as Spörer's law, which predicts the variation of sunspot latitudes during a solar cycle. *Winner – Our Sun*



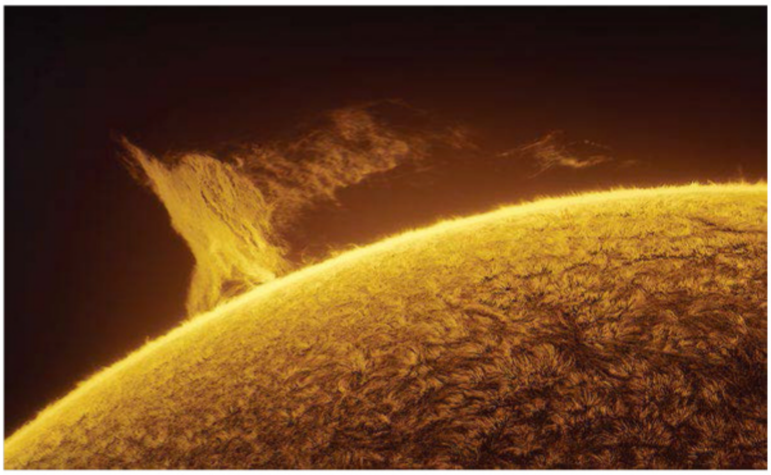
Cosmic rose (left): Judges said that Lionel Majzik's two-night composite image – which appeared to show Comet 4P/Faye splitting the emission nebula Sh2-261 in the constellation Orion – was "a truly unique composition". Also known as Lower's Nebula, this large region of mostly ionised hydrogen resembles the shape of a red rose. The comet's appearance completed the 'rose' with a 'rose stem'. The foundation frames were taken at Mayhill, New Mexico, US, in October 2021.

Highly Commended – Planets, Comets & Asteroids



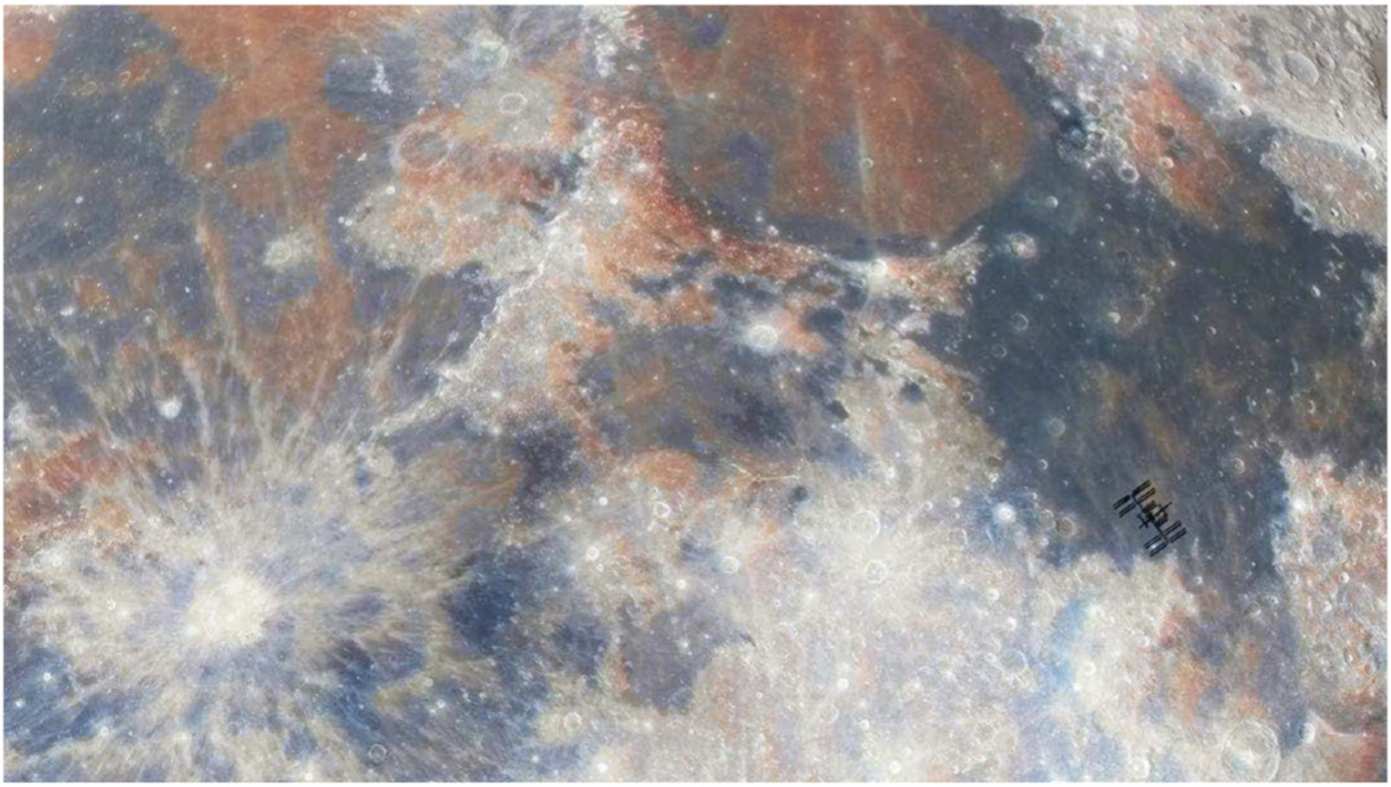
Solar tree (above): Pauline Woolley used open-source data from Solar Dynamic Observatory (SDO) to make this work, derived from her research into carbon-14 traces found in some studies of tree-ring dating (dendrochronology). "Twenty-six images of the Sun from the first part of Solar Cycle 25 have been layered to create concentric rings," Woolley wrote. "The oldest 'ring' lies in the centre while the most recent sits furthest away. Month by month, the rings expand or 'grow' to form the rings of an imaginary solar tree." The SDO captured the base images between January 2020 and February 2022.

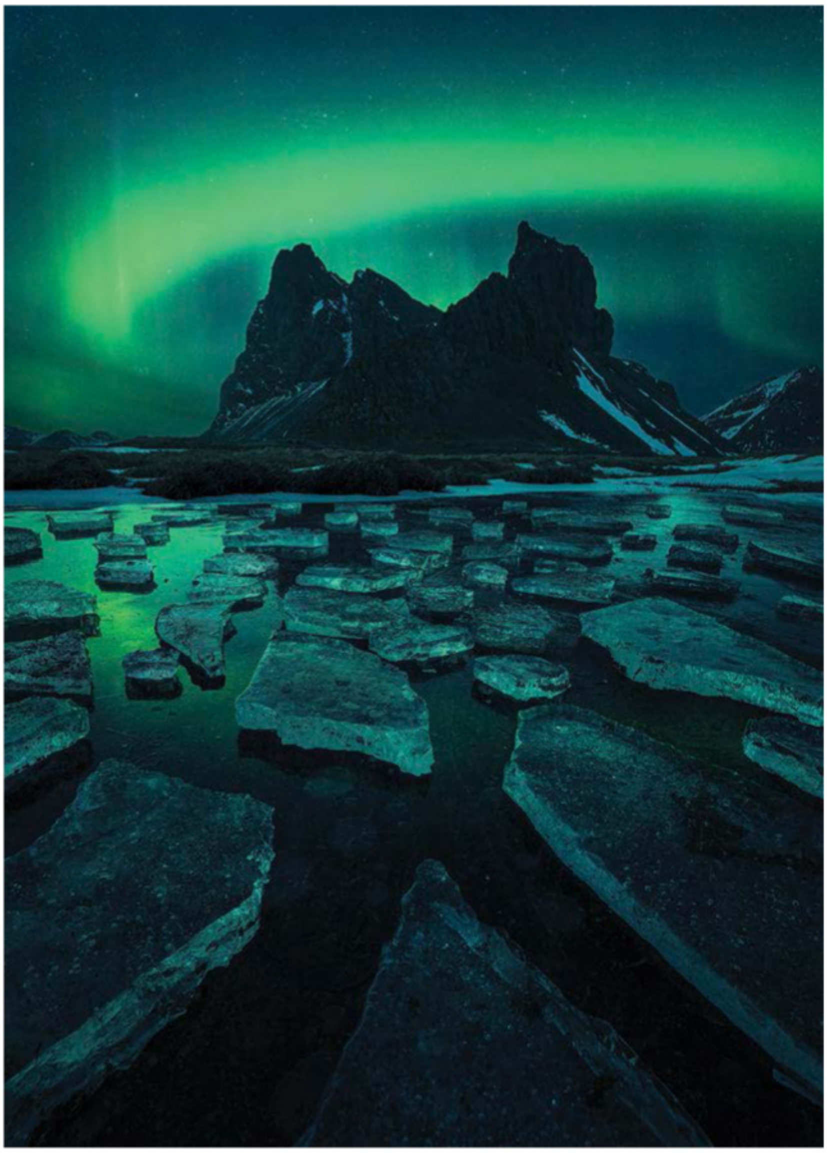
Winner – the Annie Maunder Prize for Digital Innovation



A giant in the Sun's limb (left): A huge solar prominence appears over the chromosphere (the Sun's lower atmosphere) of the limb (the apparent edge of the Sun). This giant was visible for two days in February 2022 and then erupted, throwing a Coronal Mass Ejection (CME) into space. Miguel Claro captured the image from the Dark Sky Alqueva region, in Évora district, Portugal, on 7 February 2022.

Highly Commended – Our Sun

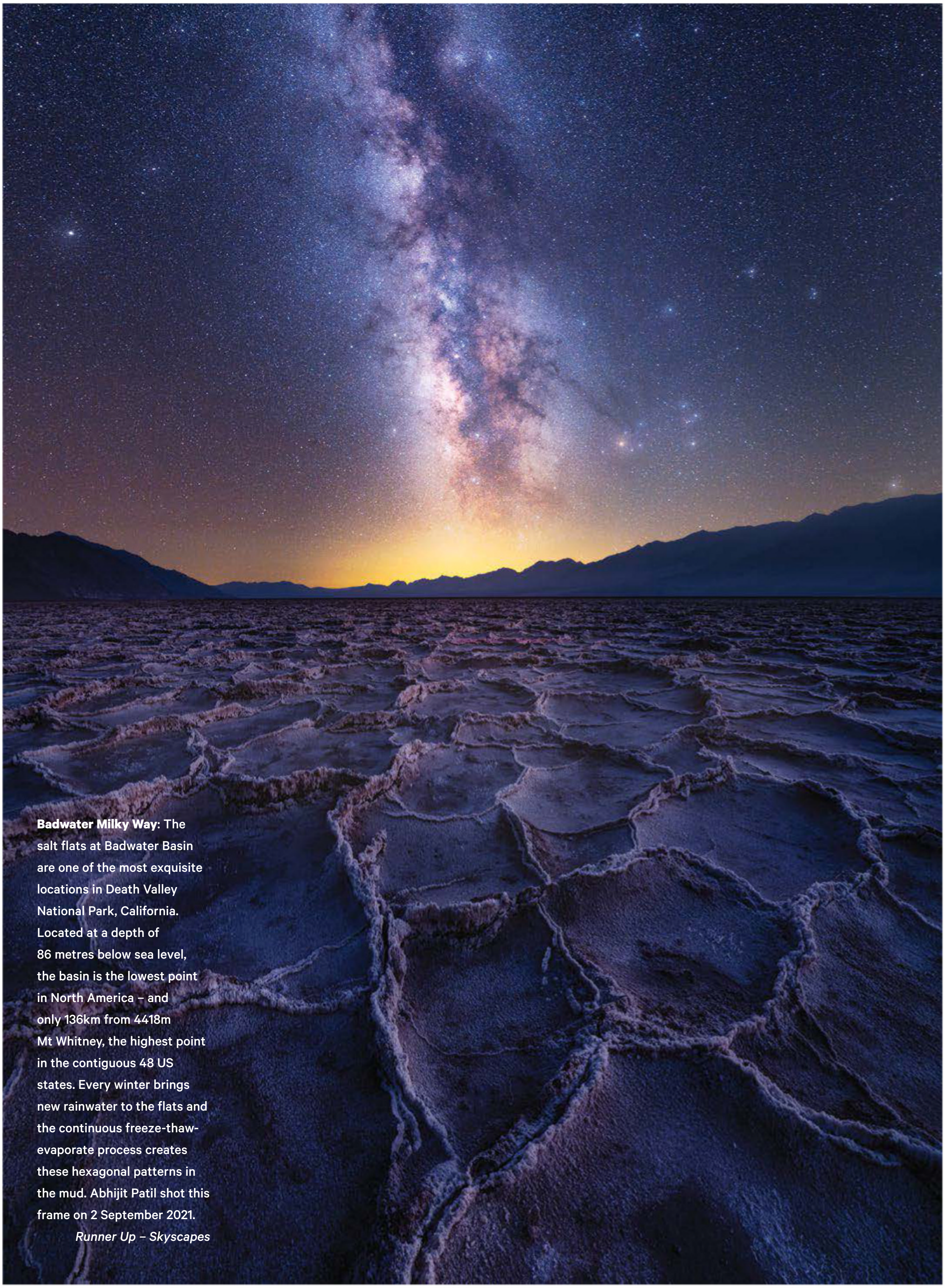




The International Space Station transiting Tranquility Base (above): On 19 January 2022, the International Space Station (ISS) was perfectly aligned between Andrew McCarthy's telescope camera in Florence, Arizona, USA, and the *Apollo 11* 1969 landing site on the Moon's Sea of Tranquility. McCarthy needed to be precisely positioned to capture the milliseconds-long moment at the perfect time. *Winner – People & Space*

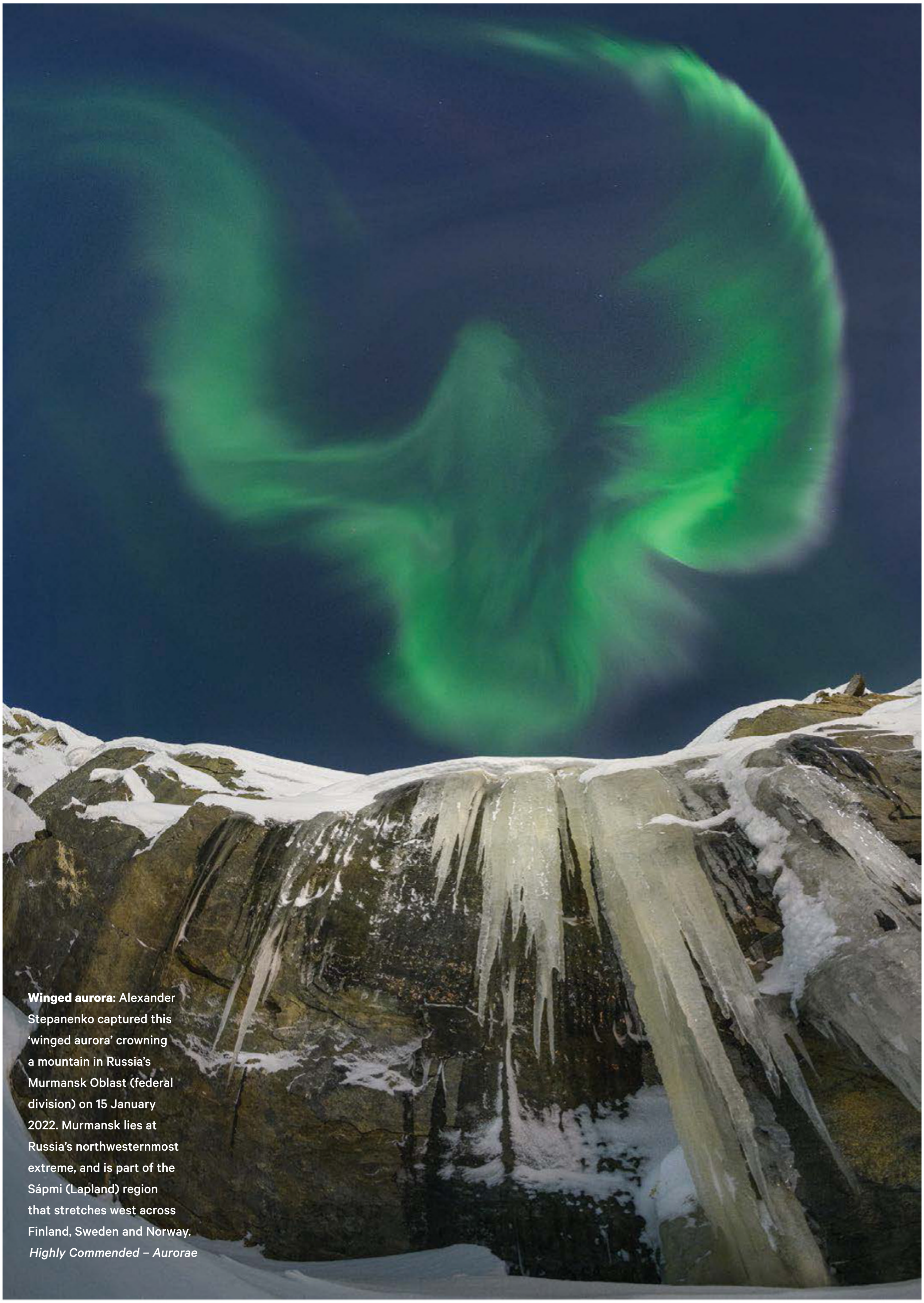
In the embrace of a green lady (left): Although the Northern Lights are most often shot in the winter months, Filip Hrebenda took this remarkable frame in east Iceland during the late spring. It shows the dancing Aurora Borealis above Mount Eystrahorn, a 756m peak composed of gabbro – a dark, jagged lava rock rich in magnesium and iron. The scene is reflected in the ice-block-strewn waters of a nearby lagoon.

Winner – Aurorae

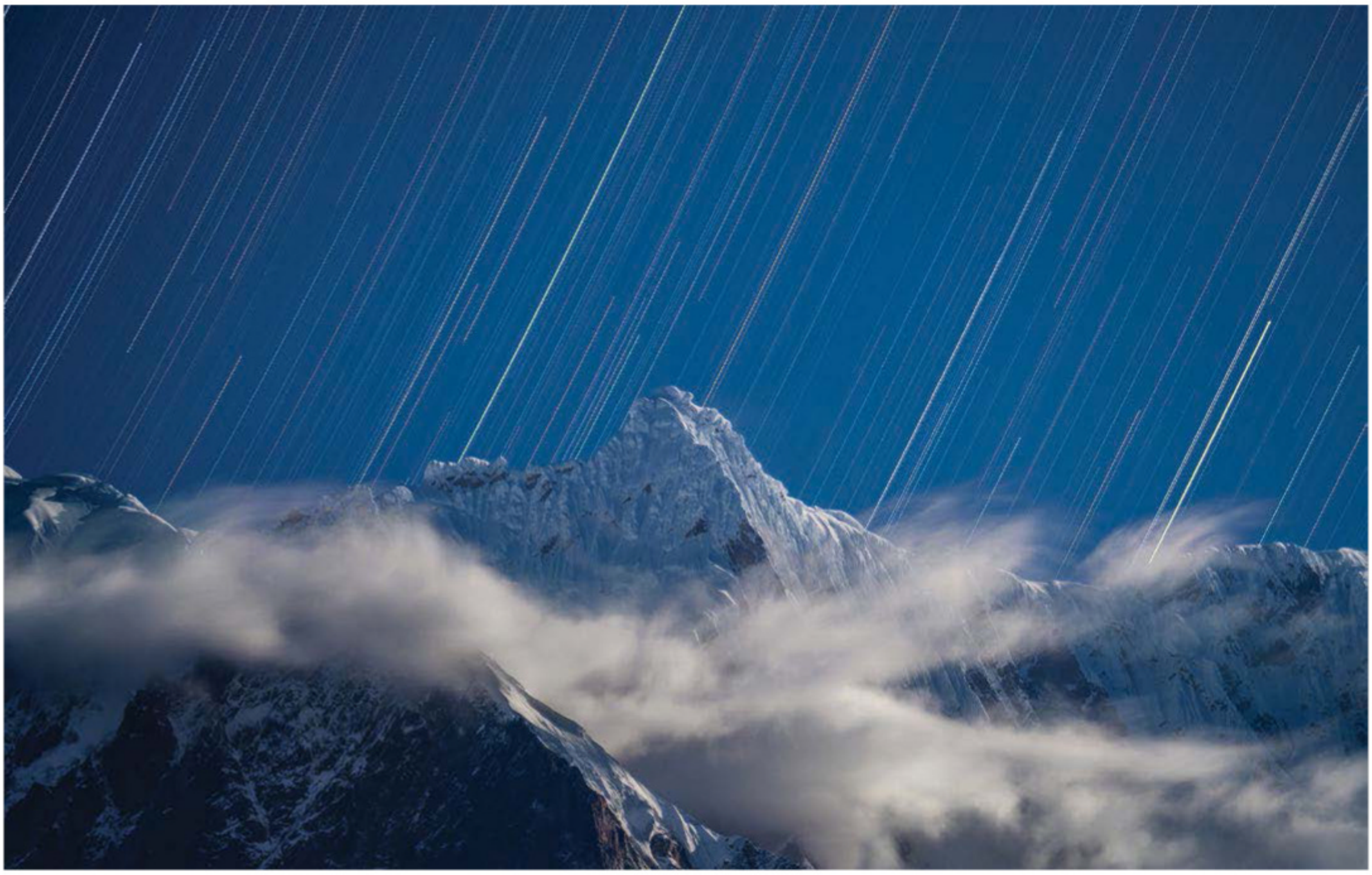


Badwater Milky Way: The salt flats at Badwater Basin are one of the most exquisite locations in Death Valley National Park, California. Located at a depth of 86 metres below sea level, the basin is the lowest point in North America – and only 136km from 4418m Mt Whitney, the highest point in the contiguous 48 US states. Every winter brings new rainwater to the flats and the continuous freeze-thaw-evaporate process creates these hexagonal patterns in the mud. Abhijit Patil shot this frame on 2 September 2021.

Runner Up – Skyscapes



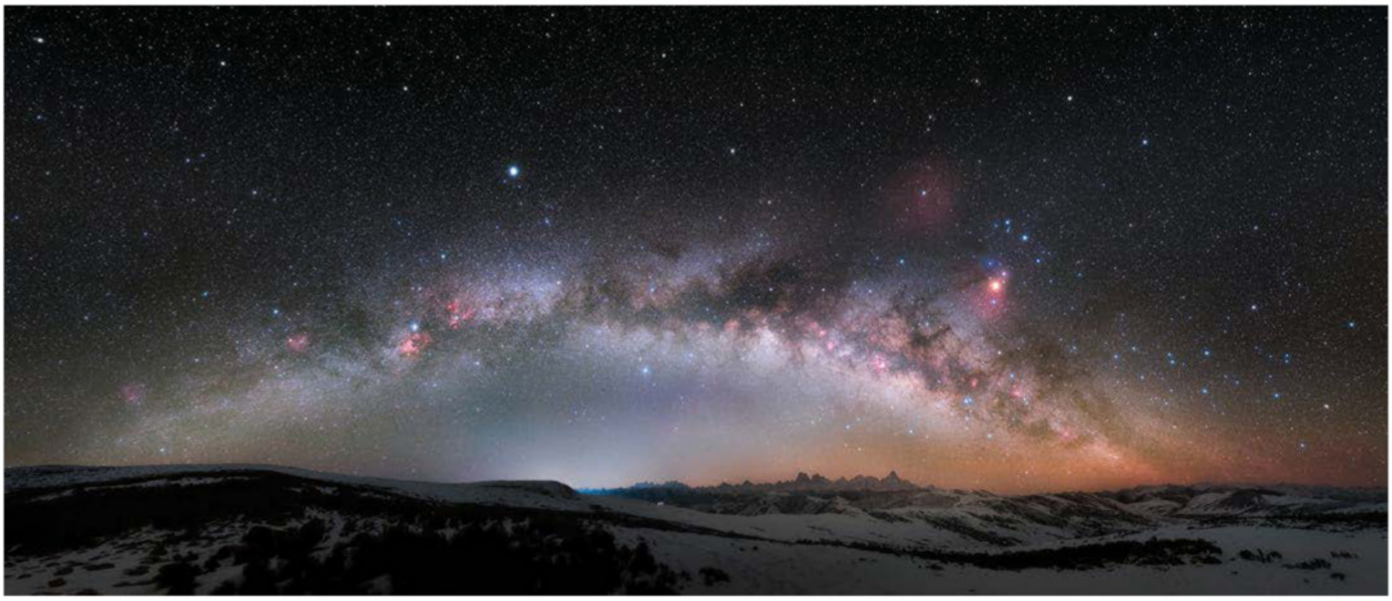
Winged aurora: Alexander Stepanenko captured this 'winged aurora' crowning a mountain in Russia's Murmansk Oblast (federal division) on 15 January 2022. Murmansk lies at Russia's northwesternmost extreme, and is part of the Sápmi (Lapland) region that stretches west across Finland, Sweden and Norway. *Highly Commended – Aurorae*



Stabbing into the stars (above): The 7782m Tibetan peak Namcha Barwa is widely thought to be the most beautiful Himalayan mountain in China; its name in Tibetan means "spear thrusting into the sky". It rises in an isolated part of Nyingchi Prefecture, in southeastern Tibet. Zihui Hu's picture is a composite of 75 30-second exposures taken on 24 December 2021. *Winner – Skyscapes*

The Milky Way bridge across big snowy mountains (below): The Milky Way rises above 7556m Minya Konka, also known as Gongga Shan, the highest peak in Sichuan China, in the early hours of 21 February 2021. Minya Konka is the world's third highest outside peak of the Himalaya/Karakoram range. Lun Deng created this composite image with multiple 30-second exposures.

Winner – the Sir Patrick Moore Prize for Best Newcomer



After diving from a speeding dinghy, scientist Scott Whiting firmly restrains a young green turtle. The animal's physical details will be recorded before it's released into the waters around Marchinbar Island in the Top End.

CREDIT

Turtle dreaming

Searching for the Wessel Islands' marine megafauna

In a remote archipelago off Australia's Top End, scientists and Indigenous rangers are collaborating to gather knowledge about the region's large marine animals, which are thought to be in decline. Story and photography by **DAVID HANCOCK**.

In the warm, shallow waters that lap Australia's Top End it's called a "rodeo" manoeuvre; where someone leaps overboard from a boat that's been following a turtle to grab and hold the marine creature. There is a real knack to catching a turtle this way, according to Kakadu ranger, Dwayne Wauchope.

"You have to get that technique right – where your hands go out automatically and grab him behind the head and tilt him up," Wauchope says. "You have to make sure your hands are not close to any rocks or coral and you don't grab him by the shell, because you can cut your hands."

A ranger at Northern Territory's Kakadu National Park for more than 20 years, Wauchope says members of his family from the Cobourg Peninsula, 350 kilometres north-east of Darwin, have been catching and harpooning turtles for generations.

"Your parents teach you from an early age," he says. "Now we have boats and all that other high-tech stuff, I don't allow harpooning. If you're not a really good harpoon person, you can hit the turtle in the lung or elsewhere and if you don't want the turtle and you let him go, he is likely to die."

There's increasing suggestion across northern Australia among Indigenous coastal communities that turtle and dugong populations are declining. At Elcho Island, traditional Yolngu owners have asked hunters to limit their take.

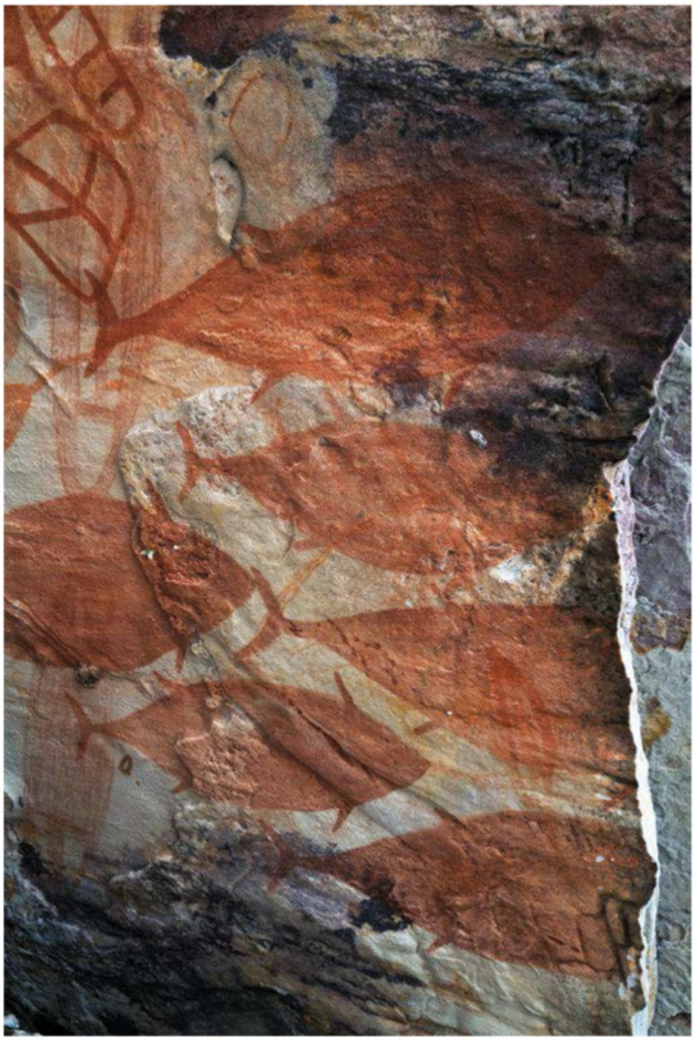
"We still eat turtle and dugong because it is better than food from the store," says David Ganambarr, a traditional owner of the Wessel Islands, which stretch north from Elcho into the Arafura Sea. "When we go out and hunt dugong and turtle, we tell everyone they can only take two turtles at one time, and with dugong – only one. If there is a funeral they can take more because we have to feed everyone involved."

Western science is sympathetic to the concerns of coastal Aboriginal people. Scientists believe climate change, rising sea levels, high temperatures, marine debris, commercial fishing, feral animals and even lights from industrial and residential developments play a growing role in declining numbers of marine megafauna. According to Charles Darwin University marine biologist, Dr Carol Palmer, it's incorrect to assume – as some do – that the decline is down to traditional hunting.

Based in Darwin, Palmer is heading up an Australian Research Council (ARC) project that brings together land and sea rangers, traditional owners, scientists, universities and government. It's a landmark partnership that links traditional marine knowledge with Western science. The aim is to establish standardised protocols for monitoring marine megafauna; to identify densities of key dolphin and sea turtle populations by recording sightings and gathering DNA samples; and to identify key habitat areas for conservation management using satellite tracking and traditional knowledge.

The project focuses on four threatened species of cultural importance: the endemic Australian snubfin (*Orcaella heinsohni*) and Australian humpback (*Sousa sahulensis*) dolphins, and green (*Chelonia mydas*) and

Kakadu ranger Dwayne Wauchope (above), assisted by his nephew 'Junior', moors a research vessel at Hopeful Bay, at the south-western end of Marchinbar Island, the largest of the Wessel Islands group. These clear waters harbour marine megafauna species including the green turtle (opposite top) and bottlenose dolphins (opposite middle). Indigenous art (opposite bottom) depicting fish such as mackerel are a feature of caves on Marchinbar Island.



> **It's an enormous venture that ranges from the Wessel Islands in the east west to the Darwin region, and includes more than 1000km of coastal and adjacent sea country.**

hawksbill (*Eretmochelys imbricata*) turtles. Other species of dolphins and turtles – along with whales, dugongs and manta rays – are being recorded and DNA sampled (if possible) during the three-year project which began last year. It's an enormous venture that ranges from the Wessel Islands in the east west tothe Darwin region, and includes more than a thousand kilometres of coastal and adjacent sea country.

Indigenous groups involved include the Larrakia rangers from Darwin, Gumurr Marthakal rangers based at Galiwin'ku on Elcho Island and rangers from Kakadu NP and Cobourg Marine Park. Palmer says Aboriginal people have noticed impacts on coastal and sea country that their parents, grandparents and

INSET: GOOGLE MAPS

great grandparents have traditionally managed and woven stories around.

"Having worked with ranger groups across the NT and the Kimberley for many years I know their information about plants, animals, weather and hotspot areas on the land and sea is so crucial to our understanding of northern Australia," she says.

"It's important to acknowledge that and to record it and make it publicly available. Important because most Australians don't realise how expansive and precise their generational knowledge is and it will definitely help us manage Australia's amazing marine megafauna."

Aboriginal people, too, are keen to exchange knowledge.

"We are noticing the numbers [of many species] are dropping because we are out there all the time," says Wauchope, who works in the South Alligator region of Kakadu.

"If we are not at sea while we are at work, then we are out at sea after work, or on holidays. When someone asks us [about our local environment] we know what we are talking about.

"Working with Carol I am learning so much more about turtles, dolphins and other marine animals. Collaboration with scientists helps me out and it helps our people when we go to meetings [with government decision-makers]; we know exactly what we are talking about and are aware of many of the things that they try to tell us. As Indigenous people, where we lack a little bit of scientific knowledge in those finer things such as life cycle and genetics, we do know a lot about these animals from daily experience and what has been handed down by our ancestors.

"There are a few things I have found very useful, for example we learn about sea grass and habitat and

> "Their information about plants, animals, weather and hotspot areas on the land and sea is so crucial to our understanding ... Most Australians don't realise how expansive and precise their generational knowledge is"

Scientists Natalie Robson (left, at left) and Scott Whiting, at right, search coastal creeks for young turtles, always with an eye out for saltwater crocodiles. Traditional owner David Ganambarr (right, at centre) guides the Robson and Whiting around Marchinbar Island. Robson (below) examines a green turtle nest from which eggs have hatched. Ready to dive (below right), Puna Cooper stands at the bow of the Charles Darwin University research vessel.

realise it's a wider thing, not just about the turtle. We walk around back home on the sand and Carol is telling us about the grasses and things, so we see what she is talking about. Yeah ... science and traditional knowledge – it's like a missing puzzle."

Knowledge shared – and multiplied

The Wessel Archipelago is a narrow strip of islands extending north-east of Galiwin'ku community on Elcho Island, for about 120 kilometres. The most northerly point is Cape Wessel, which houses a beacon to help sailors who ply the route from Gove to Darwin. The islands are low and sandy, with mangroves and heathland and have outflows of springwater. More than 55km long and around eight kilometres wide, Marchinbar is the largest island in the group.

On the western – or leeward – side, the beaches are long, flat stretches of pure white sand; coral is common and sea creatures abound. On the windward, or eastern, side, sheer cliffs rise up to 60 metres from the sea; between some of the cliffs are small secluded bays that attract nesting turtles. The islands are also home to saltwater crocodiles and it is not unusual to see their tracks circling nesting sites. The islands follow the Top End wet/dry climatic seasons and, early in the year, waterfalls cascade over the cliffs from monsoonal rain.

If the sea is smooth and undisturbed it takes about three hours to travel from Galiwin'ku to Hopeful Bay on the western side and southern end of Marchinbar Island by open boat. If a swell from the north is running it can be a laborious, drenching, hull-slapping journey that takes up to five hours. Not only are the Wessels a hotspot for nesting green, hawksbill and flatback turtles, but Marchinbar Island is home to rare terrestrial species such as the golden bandicoot (*Isoodon auratus*) and northern quoll (*Dasyurus hallucatus*). Unlike the mainland, there are no feral animals or plants on the Wessels, making the archipelago an ideal environment for scientific research.

The islands are currently uninhabited, but they were home to Yolngu Aboriginal people for thousands of years. The islands were mapped and named by Dutch seafarers in the 1600s and frequented by Macassan traders, who collected trepang from the shallows of sandy beaches and coral reefs.

> “The Marthakal mob have got stories that are nearly exactly the same as our stories and yet we live so far away from them. We learn when they hunt, how they hunt, how they call country; it’s good for us.”

During World War II the Australian Government set up observation posts at Cape Wessel and at other places on the islands. In 1943, a minesweeper, the *Patricia Cam*, was attacked and sunk by a Japanese float plane; several naval crew members and Aboriginal pilots made it ashore and were rescued.

In 1944, nine coins were discovered south of Jensen Bay on Marchinbar Island. Four were identified as Dutch, minted between 1690 to 1780; five with Arabic inscriptions originally came from the Sultanate of Kilwa in east Africa and were created sometime between the 10th and 14th centuries. No-one knows how they got there.

Carol Palmer began working at Marchinbar in the 1990s, researching the golden bandicoot population – the species was close to extinction on the mainland. The relationship Palmer developed with traditional owners and Indigenous rangers enabled her and other scientists to establish the ARC project at Hopeful Bay in 2021.

“I think the Wessels is a unique archipelago,” she says. “It is certainly a hotspot for dolphins, some whales, manta rays and, in the past, it has been a well-known area for green turtles. But last year when we did our first survey there, and this year, the turtle numbers were very, very low.

“We did catch one large female and put a satellite tag on her and we monitor where she is going every day. She is still in the area but moving quite a way out. However, marine megafauna is not just turtles, this is a multi-species project.

“The other part of the project is an exchange between ranger groups. Kakadu rangers came to the archipelago last year and again this year. Dwayne Wauchope and Puna Cooper shared knowledge from Kakadu, with Gumurr Marthakal rangers. Their expertise and understanding about how to do a lot of this work is really substantial. All the rangers have emphasised to us how important the ranger exchange is and it’s the recording of not just western science but the traditional science from different areas.”

Wauchope and Cooper say the exchange of knowledge has been eye-opening.

“The Marthakal mob have got stories that are nearly exactly the same as our stories and yet we live

TURTLE FUTURES

Northern Territory waters are graced by six of the world’s seven marine turtle species – green (*Chelonia mydas*), olive ridley (*Lepidochelys olivacea*), hawksbill (*Eretmochelys imbricata*), leatherback (*Dermochelys coriacea*), flatback (*Natator depressus*), and loggerhead (*Caretta caretta*).

Marine biologist Carol Palmer (above) has been studying them and other Top End marine megafauna for decades – and she doesn’t like the look of the future.

“Certainly traditional owners and rangers are worried about the numbers of turtles and green turtles in particular,” she says.

Palmer thinks the population reductions are probably down to some clear changes. “Definitely, sea level rise, and sea temperature rise.”

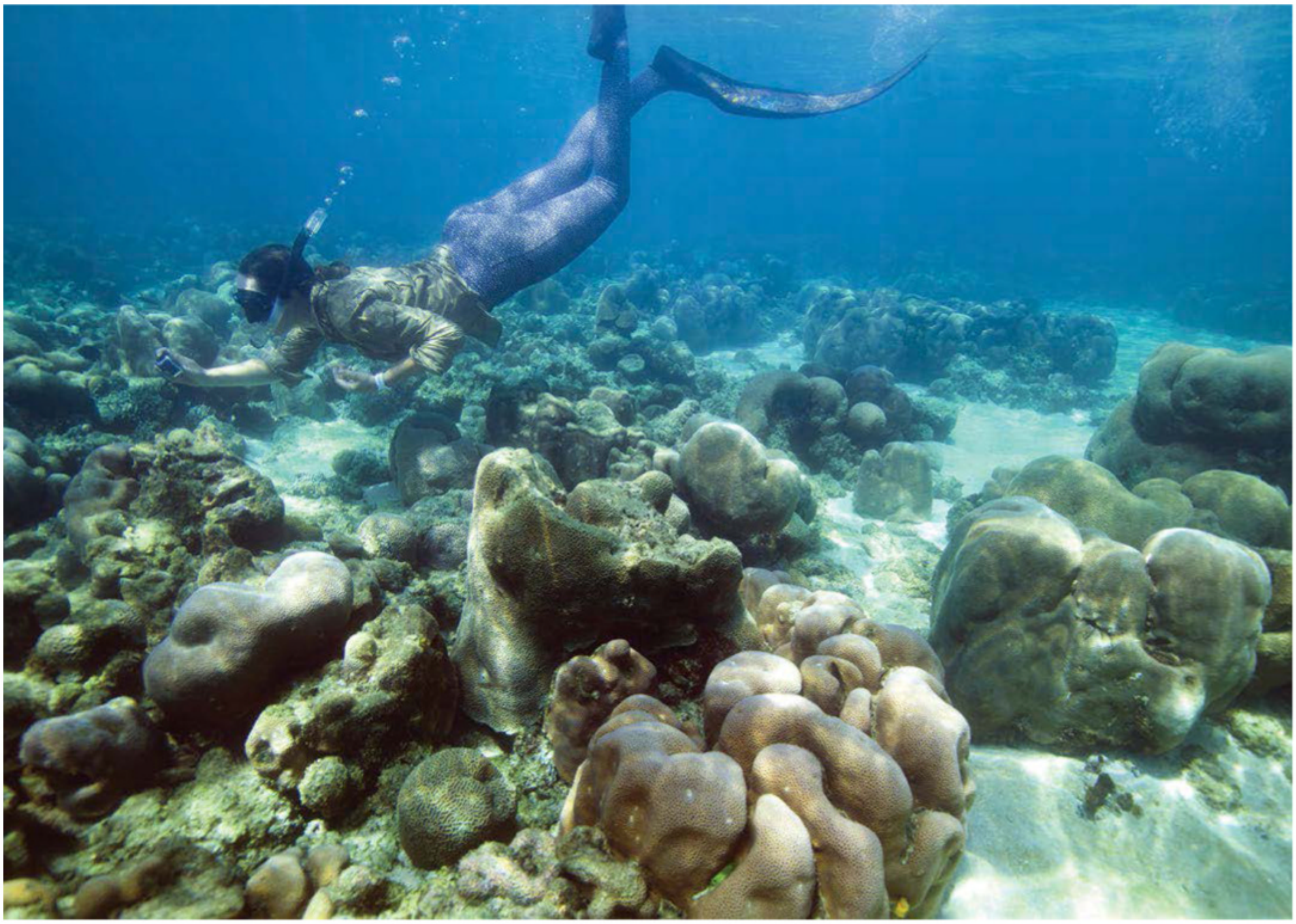
She says more and more rangers in these remote locations are talking about sea level rise.

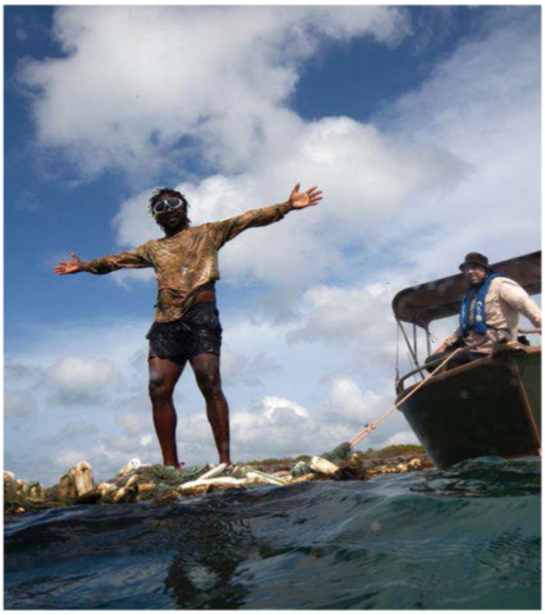
“It was their parents or their grandparents or their great-grandparents who know these areas,” she says. “And we could be just talking about small little islands, or many of the beaches.

“But also the temp rise with the nesting turtles. This is coming out more and more certainly… for the green turtles, which is what we’re focusing on, and the hawksbills.

“The temperature is really, really increasing here in the Northern Territory, and that means that of the eggs that hatch, 99% are going to be female and 1% male.”

Once pristine, many of the beaches (opposite top) in the Wessels group are littered with marine debris, mainly plastic products, which wind and currents swirl from the north into the Gulf of Carpentaria, then across the Top End and out to the Indian Ocean. Traditional owners are deeply worried – the problem now outstrips the ability and resources of many communities to manage. In spite of the marine waste, waters surrounding the Wessels (opposite bottom) are rich with coral and marine life and much clearer than the murky waters near Darwin.





so far away from them – the stories are a little bit different in the details but very similar," Wauchope says. "We learn when they hunt, how they hunt, how they call country; it is good for us.

"I have been in Kakadu so long and that is what we are missing, that exchange of knowledge – it just makes you into a better person and a better ranger as well, and it is reassuring to know they are having the same struggles we have."

An ocean of waste

As pristine as it is, the Wessel Archipelago faces major problems, foremost among them marine debris.

"I started work on Marchinbar with golden bandicoots in the 1990s and worked through to 2011," Palmer says. "There was virtually no plastics or ghost nets during that time. In 2016 we went back to check the bandicoots and we noticed the amount of ghost nets and plastics had increased substantially. In 2021 it had increased even more substantially. I had never seen so many plastics and ghost nets across the NT."

Dr Scott Whiting, Principal Research Scientist, Marine Science, with the Western Australia Department of Biodiversity, Conservation and Attractions, accompanied Palmer to the Wessels this year. He says the incidence of marine debris from the western side of the Gulf of Carpentaria all the way to Cobourg Peninsular probably ranks as some of the world's worst.

There are turtle nesting beaches littered with plastics and the remains of fishing nets. At sea, discarded nylon nets tangle to form their own ecosystems that float and follow currents; they trap, injure and kill all kinds of marine animals. These ghost nets can reach down for metres and trail for hundreds of metres, and can entangle marine creatures for years.

The Plastic Soup Foundation, an international body dedicated to raising awareness and fighting plastics pollution at sea, claims hundreds of millions of marine animals annually are killed or injured by ghost nets.

"Marine debris is fairly invisible to us until it washes ashore," Whiting says. "It affects turtles when they are very small when we don't see them – so it is not the turtles here in the shallows that are affected by marine debris. It is the turtles being killed out there at sea. We probably don't know what we are missing, because they don't end up arriving.

"We do see all the life stages of species caught in marine debris, in the nets, because they are foraging on the surface of the ocean and those nets provide a micro habitat. Because they are searching for food on the surface, they will eat all the bits of plastic floating along. That is a really big issue and a problem that is as much a foreign affairs issue as a conservation issue because it's ubiquitous around the world. It just can't be solved easily and it will take many decades to reduce the pressure."

Carol Palmer (top) has an eye out for a variety of marine animals as the group of scientists and rangers patrol the coastline. To emphasise its mass (above), Gumurr Marthakal ranger Marcus Lacey stands atop a ghost net that has drifted onto coral at Marchinbar Island. The extensive Yolngu knowledge of traditional owners (above right) David Ganambarr, at left, and James Djamu, right, help scientists better understand the region and local marine life.

Much of the debris in Australian waters and on our beaches comes from neighbours to the north; most of it is swept into the Gulf of Carpentaria, across the Top End and out into the Indian Ocean. It deeply concerns traditional owners, because their ability to manage the problem has gone beyond the scope of many communities. Even though coastal ranger groups regularly collect plastic debris along beaches, most ghost nets are too heavy to deal with – it's been suggested the Royal Australian Navy use their vessels to tow the nets ashore to be destroyed.

Marine debris might be the current issue that's challenging their capacity, but Indigenous ranger groups play a major role in marine management right across northern Australia, from Cape York to Broome.

“We do see all the life stages of species caught in marine debris ... That is a really big issue and a problem that is as much a foreign affairs issue as a conservation issue because it’s ubiquitous around the world.”

“Overall, it has to be the most positive movement I have seen for Indigenous social outcomes in terms of education, health, youth justice and conservation,” Whiting says. “Here is a pathway where kids can see where they could end up, and their role models are probably one of the biggest benefits I have seen.

“I think putting funds into them now is a miniscule amount than if government had to do it in another way. Many communities struggle to find an industry to support themselves but I think we have already got the industry – land and sea management across Australia that is done by people who want to be here and have ownership in the area and are going to be here for generations.”

Alliances between scientists, traditional owners and Indigenous rangers are only going to strengthen over time. “Hopefully this research program will be able to develop a proper on-ground working program for all the sea ranger groups in their traditional sea country,” Palmer says.

“It will probably be different in many cases and will not be like having one policy that will cover everything ... that will not work. The more remote things are, the more difficult and expensive management becomes; to have one year’s funding will not work.

“What we need is long-term funding for management of marine megafauna and to help step rangers, traditional owners and kids through the process.” ◉

DAVID HANCOCK is a writer and photographer based in Darwin. This is his first story for *Cosmos*.

CRAVED IN SPACE

Almost stranger than fiction: an Adelaide pond weed may pay its own way to Mars, writes **JAMIE SEIDEL**.

Man cannot live on bread alone. Nor woman chocolate. But nobody can survive without bacon. And that's a problem for life in space.

A crisp crunch. A fresh tang. The bite of spice. These are the things astronauts aboard the International Space Station (ISS) quickly come to crave.

Sustenance, it turns out, isn't enough for survival.

Little wonder the most-commonly requested delivery item in space is a crisp, crunchy apple. Or a zingy sausage.

"Eating is a whole sensory experience," says Associate Professor Jenny Mortimer, from the University of Adelaide's School of Agriculture, Food and Wine. "It's about flavours and textures, smells and temperatures." It's also inherently social.

"Meals are something that brings people together," Mortimer says. "Astronauts have been known to take plants out of their research containers and fasten them to the tables where they sit together – there's a real cultural and ritual thing going on there." Plants will help you breathe. They will keep you sane. But, mostly, they will feed you.

"We talk about people going to Mars but we've got a lot of work to do before we get there," says Australian National University Associate Professor Caitlin Byrt. "We need to be able to grow things both in space and in facilities on the lunar and Mars surfaces. The know-how for that doesn't exist yet."

Put simply: we can't meet the nutritional needs of a long-duration space mission – let alone service the emotional associations with food – with just tins, vacuum packs and protein paste.

Livestock is out of the question. And our crops, like the humans that tend them, didn't evolve to live in zero gravity.

In November, the Australian Research Council (ARC) granted $35 million over seven years to establish a new Centre for Excellence in Plants for Space (P4S). Including money from other partners, this brings the total investment in P4S to $90 million.

Eventually, some 400 researchers across Australia will strive to give potential space-faring plants "the right stuff".

Mortimer already has a contender.

It can cope with the cold. It dismisses drought. And when the going's good, it grows very fast.

That's why the descendants of a weed growing in an ornamental pond at Adelaide University's Waite Research Institute could end up on Mars.

LEFT: GREG BARTON / MIDJOURNEY. DUCKWEEDS: IAIN SARJEANT / GETTY IMAGES

Space for life

Astronaut Scott Kelly fell ill in orbit aboard the ISS. His body was struggling to adapt. It turned out flowers were the best medicine.

“They sent zinnia flowers to the space station for no other reason than they were pretty,” says Mortimer. “[Kelly] got massively invested in the survival of these flowers. He used to wipe them down each day to try and decontaminate them. Just the psychological thing of having this beautiful flower to take care of made his trip for him.”

Then there’s the phenomenon of menu fatigue. We all know the feeling. We can get tired of even a favourite food after having too much of it too often. Astronauts are prime candidates for menu fatigue. They eat everything they’re given. And they’re given meals carefully designed to provide everything they need. But they still end up losing weight.

“It’s all just a bit ‘brown’,” says Mortimer. “They just love having something fresh. They had a chilli-growing challenge recently and they all ate space tacos. And they talk about it as being the best food they’ve ever eaten.”

So, for future space travel, plants can supplement raw nutrition with the vital spice of life.

“But upon arrival at the Moon or Mars, we would need to get to the point of meeting calorie demand,” Mortimer adds.

That needs industrial-scale production. And industrial-strength plants.

The right stuff

It costs a ballpark $2400 to put one kilogram of anything into low-Earth orbit. That blows out to about $470,000 for the Moon. And getting it onto the lunar surface is an estimated $1.9 million.

That’s why doing more with less is a matter of life or death.

Plants can’t afford to be passengers. They must be continually productive. They must be compact. (This won’t mean the return of the square watermelon.)

“They’ve got that long period of growth where you’re not getting any harvest at all,” Mortimer explains. “You’ve got to calculate very carefully how much plant takes up how much space to produce how many calories per person, because you can’t afford to run out.”

“DUCKWEED IS WHAT I CALL A CHASSIS FOR ENGINEERING. IT’S THE STARTING POINT. NOW WE JUST HAVE TO FIGURE OUT WHAT WE CAN ADD INTO THAT”

That makes strawberries prime contenders. And carrots.

“Everyone likes them,” Mortimer explains. “Not only are they nutritious, they’re also delicious and colourful.” They’re also very efficient: You can eat the leaves. And that meets the “zero waste” mantra dominating every aspect of life in space.

So astrobiologists are seeking the perfect ‘template’ plant. One that meets most of the criteria for life in space, but that can also be adapted to provide the rest.

“I’m biased in that I have a favourite plant already,” Mortimer says. “It’s called duckweed. It’s fantastic, because it’s basically flat, and you can eat the whole thing.”

The fast-growing green leafy vegetable – Lemnoideae subfamily – floats on a very thin layer of water. And it’s been part of the diet for people in many parts of Asia for millennia.

“It has all the amino acids humans need, starch, fatty acids, pretty much every vitamin apart from B12 and D,” says Mortimer. “They say it has three times as much protein as spinach.”

But duckweed is up against some stiff competition.

Israel’s “Space Hummus” project put 28 chickpea seedlings into orbit earlier this year. Lettuce, cabbage and kale have been up there on and off for a while. But Mortimer thinks duckweed has an edge: it tastes like whatever you grow it in.

SHIP PORTAL: GUILLAUME / GETTY IMAGES. ABOVE: ESA / ALEXANDER GERST

It's not easy being green: Early plants in the ISS's onboard Vegetable Production System – aka Veggie – experiment were subject to instruction manuals. When the zinnia (above right) started wilting, astronaut Scott Kelly pointed out: "I think if we're going to Mars, and we were growing stuff, we would be responsible for deciding when the stuff needed water. Kind of like in my backyard, I look at it and say 'Oh, maybe I should water the grass today'." Kelly paved the way for more autonomous gardening on the craft, such as (opposite top right) astronaut Serena Auñón-Chancellor's harvest of red Russian kale and dragoon lettuce in 2018, which the crew enjoyed with balsamic vinegar. Associate Professor Jenny Mortimer (above left) thinks that the humble duckweed she's displaying could provide a plentiful and tasty protein source for our first space colonists.

ABOVE: NAOMI JELLICOE PHOTOGRAPHY / NEWSPIX. RIGHT: NASA

"My colleague in the US has grown it in bacon flavour," she quips.

Mmmm. The Homer Simpson dream: unexplained bacon.

Multi-functional flora

"We're going to take a couple of suitable plant species and try and use them to cover as many of our requirements as possible," says Mortimer.

What would such a plant look like? For openers, it's a matter of identifying what properties are necessary, and, further, determining if these already exist in nature.

Then researchers need to work out if these can be bred or designed into just one resilient plant.

"Duckweed is what I call a chassis for engineering," says Mortimer. "It's the starting point. Now we just have to figure out what we can add into that."

Students are working on ways to make it produce vitamin D and improve its vitamin A output. One is looking at growing bioplastic construction materials. Others are trying to get the plant to synthesise pharmaceutical compounds such as aspirin.

Byrt, a biological engineer, says it's highly likely plants can become multipurpose factories – up to a point.

"With duckweed, it's handy you're dealing with something that's already edible," she says.

"There is a range of plant features you may want to take advantage of on space missions. Having a diversity of plants will be an advantage." Some plants have evolved to optimise the production of starch or sugars. Others do oils or fibres.

"You could hypothetically engineer a plant that could switch from one kind of oil to another – such as vegetable fats to Omega 3," Byrt adds.

"With aspirin, for example, it is a chemical that comes from willow bark. So I can't see why you couldn't engineer new plants and reprogram their existing biochemical pathways to produce related chemical products." Ultimately, the idea is to give plants useful "genetic circuits": the ability to switch the production of different compounds on or off according to demand.

"The ISS is only 400 kilometres away, and it's hard enough to treat those astronauts," says Mortimer. The Moon is 384,400km distant. Mars is 100 million km.

"So you're not going to be able to take a pharmacy with you, or keep it fully stocked," she says. People are also going to be in short supply. And time for maintenance will be scarce.

"We're going to need automation. So, to what extent can we roboticise everything?"

And how much can you squeeze out of every plant?

"We've basically got to track every molecule of carbon, every molecule of water, make sure we know where it's going, where it's coming back," Byrt adds. "The same for every molecule of nitrogen. It focuses your mind on how many resources you are really using – how much energy you're using." It's the ultimate expression of a circular economy.

In space, it's a matter of life and death, Mortimer says, "but it relates back to our agricultural problems on Earth as well: climate change is happening at an alarming rate. And conventional ways of doing things can't keep up."

As associate Professor Caitlyn Byrt (above left) points out, plants are "multipurpose factories", providing air filtering and textiles in addition to nutrition. Also morale, as Expedition 65 flight engineers (above, from left) Mark Vande Hei, Shane Kimbrough, Akihiko Hoshide and Megan McArthur, show. They're posing in 2021 with the first chilli peppers grown in space as part of the Plant Habitat-04 investigation – and served in "the best space tacos yet". This year, Expedition 67 astronauts (opposite top left) Jessica Watkins and Bob Hines explored soilless methods of growing plants as part of the XROOTS project.

Germinating knowledge

We've already learnt a lot from two decades of near-permanent life in orbit. "One is that plants are pretty resilient, and things we'd expect to be a problem are not," says Mortimer. "But also that all species don't behave the same way."

How would plants cope not knowing which way was up? Would they, in the absence of gravity, become a tangled ball of roots, leaves and branches?

"It turns out if you provide light from above, most plants go – okay, there's no gravity, but I can still grow towards the light," says Mortimer. "It's not true for all. But it is for most."

Astronauts are pretty much the busiest humans on or off the planet. Researchers only get to book a fraction of their time. And only one of them has been a plant molecular biologist: that's put a limit on the complexity of orbital plant experiments.

"Although we've made a lot of progress, it's still comparatively limited," says Mortimer. "And honestly, a lot of the work up until now has been about more the technology infrastructure than the plants themselves."

Those infrastructure problems are not insignificant. How do you control how water moves in microgravity? Its behaviour is weird: it's globby and sticky. It tends to clump around plant roots – and that convinces the plants they're drowning.

Another issue: how do you balance the plants' atmosphere? They don't like too much carbon dioxide (nor do humans). And CO_2 levels on the ISS are four times higher than what would normally make a person drowsy.

But plant-informed technology is already solving these problems in space.

Water recycling filters aboard the ISS used to get clogged and degrade. Astronauts got sick from the contaminants that slipped past.

"You could say we're a bit obsessed about a type of membrane protein called aquaporins," says Byrt. "They're in all different kingdoms of life. They have a range of different purposes."

In trees, they help to draw moisture through the root system and into up to 100 metres of trunk and branches – all the while distributing specific nutrients where needed. In human kidneys, they help sift up to 200 litres of blood each day to keep water and mineral levels optimal.

A Danish company – Aquaporin A/S – has now successfully coopted the billions of years of evolutionary improvement that went into aquaporins and translated it into new filtering membranes capable of extracting pure water from urine.

No triffids today

Soil, and the rich microbial life within it, turns out not to be a universal necessity. Some plants can do quite well without it. Others only need an alternative.

"Plants that need a microbiome get something out of it they couldn't get otherwise, like nitrogen or phosphates," says Mortimer. "But if we're already providing all that to them, then – in theory – we can grow all these plants in sterile aseptic conditions."

But space isn't a sterile environment.

One only needs to look at the filmy layer of microbial slime that coats just about everything

FROM LEFT: UNIVERSITY OF ADELAIDE, NASA X 2

aboard the ISS. In just 20 years, it's evolved to be a new species.

And that raises a whole new set of questions.

"Humans will be there, and we're walking Petri-dishes of just about every kind of bug you can imagine," says Mortimer. "So if you've completely cleaned out the microbial population on the plant itself, do you increase the risk of human bacteria adapting itself to take up that space? You've opened up an ecological niche, just as you do when humans take antibiotics."

It's an issue international space agencies are taking seriously. And they're keen to figure it out.

They don't want infestations of weeds on Mars. Nor fields of fungi. "We've learnt from human exploration and colonisation in the past that people make a lot of mistakes," says Mortimer. "So we're going to have to be very cautious."

Branching out

Water is heavy. Soil is heavy. Both are terribly messy, even when not in zero gravity.

That's where science fiction falls down. There won't be giant glass domes spanning vast, green open spaces under the light of 100 billion stars.

Fortunately, hydroponics and aeroponics appear to work well in orbit. That means stacked industrial racks of self-contained arboretum shelves are viable.

Each drawer will be a closed, controlled environment. A tiny fraction of the water you would normally use can be delivered directly to the roots. And this can be primed with whatever nutrients a particular plant needs at any particular time.

"That's why some of the Australian companies that work in this closed environment, agricultural space are interested in collaborating on space projects," says Mortimer. "They can see the very close links between efficiency in space and the effectiveness of vertical farming on Earth."

Early calculations suggest a 2m square by 2.5m high cabinet of tightly packed duckweed could sustain a single person with a full-protein diet.

At first, it may only produce a protein shake. Ultimately, it may simulate meats and cheeses – and manufacture the thread needed to mend a torn shirt.

But much more research is needed. Every aspect needs to be measured and tested, every challenge understood. "At first you do as little as you can get away with so that people can survive," says Mortimer. "Only then can you gradually start to build out into what you ultimately need.

"If you want to colonise the Moon, if you want human exploration of Mars – you're going to need plants. There's no two ways about it." ⊙

JAMIE SEIDEL is based in Adelaide. His story on mining rare metals appeared in Issue 96.

RIGHT: DEAGOSTINI / GETTY IMAGES

Hear more about space food on *The Science Briefing*

Wizards of Oz

DAILY HERALD ARCHIVE/SSPL/GETTY IMAGES X 2

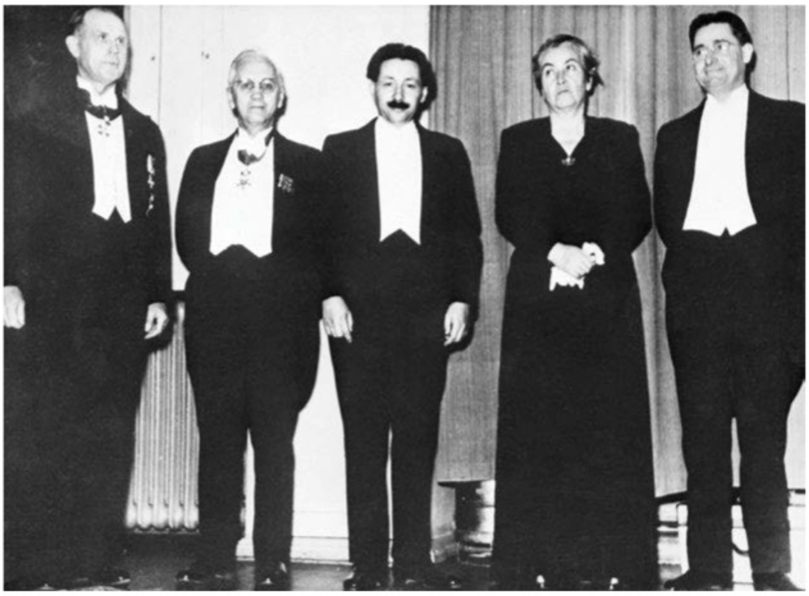
Australian scientists played leading roles in two key inventions of the World War II era. **BRETT MASON** recreates their extraordinary pioneering phases.

In the summer of 1941, within a few weeks of each other, two Australian scientists – Howard Florey and Mark Oliphant – flew from a besieged Britain, across the grey Atlantic, bound for America's hopeful shores.

Old friends from Adelaide and now world-renowned in their fields, they were unaware of each other's top-secret mission. Each carried a small yet priceless cargo, among the most critical and consequential ever carried from the Old World to the New, the fruit of revolutionary breakthroughs crowning decades of scientific work.

They were flying at perhaps the most desperate time in the war for Britain, hoping to persuade a neutral United States to lend its seemingly inexhaustible industrial might to the cause of freedom – to take their inspired concepts and transform them in the white heat of American technology into mass products to fight and win the war against Hitler.

These two flights changed the course of the Second World War. Thanks to the imagination and persistence of these two Australians, critical inventions were developed and deployed in time to play a decisive role.



Alexander Fleming (left, second from left) discovered penicillin in 1928, but it was his 1945 Nobel Prize for Physiology or Medicine co-winners – Ernst Chain, centre, and Howard Florey, at right – who turned it into an effective drug that would save countless lives. Florey and Chain industrialised penicillin production, from growing *penicillium* mould in culture flasks (opposite right) to purifying and refining it (opposite left).

BETTMAN/GETTY IMAGES

At the outbreak of war, there were a few known ways to generate microwaves but none suitable for battle-ready radar. The most promising was the 'klystron' invented in 1937 by American brothers Russell and Sigurd Varian at Stanford University and improved by Oliphant. The klystron was essentially a vacuum tube with a cathode at one end, from which an electron beam was shot to amplify a high-frequency radio signal passing through the tube.

Another method for generating microwaves was the magnetron. The first simple prototype was built in 1920 in the United States and subsequently replicated independently over the next two decades in several other countries. This device also consisted of a glass vacuum tube. The tube was surrounded by a magnetic field, which caused the electrons shot from a cathode to follow curved – as opposed to straight – paths along the tube. The magnetron could produce microwaves of a centimetre in length at 30 or 40 watts, just about enough to power a weak light bulb. Only a tenth as strong as Oliphant's klystron, it seemed unlikely ever to power workable radar.

This was the device passed to two members of Oliphant's team: the unimpressed Randall and Boot. John Randall was 34, with a creative mind and discipline for hard work. He was inspired by the Adelaide-born Nobel laureate Lawrence Bragg to train as a physicist (the world of science still being relatively small, their paths would cross again after the war, when Randall's team at King's College collaborated with James Watson and Francis Crick from the Cavendish Laboratory, under Bragg's leadership, to successfully model the structure of DNA). Harry Boot, 12 years younger than Randall, was still working towards a doctorate under Oliphant's supervision. Young and impetuous, he was particularly annoyed at being assigned an unpromising project.

Marooned in a small room behind a lecture theatre, Randall and Boot built their own magnetron and pondered how to increase the meagre power output. More than 35 years later the two recalled: "Fortunately we did not have the time to survey all the published papers on magnetrons or we would have become completely confused by the multiplicity of theories of operation". Unburdened by the furrows of previous practice and theoretical clutter, Randall and Boot asked themselves instead if the best features of both the klystron and the magnetron might be combined to produce a superior next-generation device.

Randall recalled rummaging through a second-hand bookstore on his recent summer holidays with his family in the Welsh seaside town of Aberystwyth. There he came across a copy of HM Macdonald's seminal 1902 book *Electrical Waves*. Not typical summer holiday reading perhaps, but it sparked Randall's imagination. In the book, Macdonald detailed the great German physicist Heinrich Hertz and his famous electric 'spark-gap experiment'. Hertz was the first to produce high-frequency radio waves and then, as they oscillated through a loop of copper wire, detect them in the form of a spark jumping a minute gap in the loop.

> "Fortunately we did not have the time to survey all the published papers on magnetrons or we would have become completely confused by the multiplicity of theories of operation."

While Hertz's observation inspired the first radio transmitters, the wire technology only generated short pulses of radio waves, which restricted it largely to sending Morse Code. The technology was

To expand Birmingham University's expertise in physics, Mark Oliphant (right, pointing to colleagues) planned to install a 60-inch cyclotron there by the end of 1939. But World War II intervened, and the machine – shown here in 1945 – wasn't operating until 1948.

superseded in the early 1920s by vacuum tube transmitters able to produce the continuous waves used to carry sound in contemporary radios. But Randall was nevertheless intrigued. If high-frequency radio waves could be generated across a gap in a wire, might it be possible to generate them in three dimensions – in other words, across the gap inside a metal cylinder?

Randall's musty book also detailed a calculation that caught his eye. Macdonald showed that the length of radio waves produced would be 7.94 times the diameter of Hertz's loop. So, asked Randall, would that also apply to the diameter of a metal cylinder?

He and Boot decided to find out. To achieve Oliphant's target of a transmitter that would produce 10-centimetre wavelengths (thought to be optimal for radar) they rounded up Macdonald's figure to 8 and calculated that the diameter of the tube would have to be about 1.2 centimetres.

The next step was pure genius. One afternoon in November 1939, the young men had an idea: why only one 1.2-centimetre-wide tube – why not a number of them, say six, placed around an electron beam-producing cathode? The power output would be multiplied, generating much stronger waves. Randall started to scratch a design on the back of an envelope while Boot did the calculations to create the first hazy sketch of arguably the most consequential invention of the Second World War. British radar pioneer Sir Robin Watson-Watt would later call the document 'The Magnetron Memorandum'. It was "a communal manifesto for the Centimetric Revolution in Radar".

The next step was pure genius. One afternoon in November 1939, the young men had an idea: why only one 1.2-centimetre-wide tube – why not a number of them, say six?

Through Christmas 1939, Randall and Boot laboured day and night over their secret design. They paused only once, to move to a newly built facility that Oliphant had helped secure: the Nuffield Research Laboratory. As quickly as they could, they gathered the necessary equipment. Oliphant arranged for a couple of transformers and rectifiers to convert the common alternating current into the direct current needed to power the new machine.

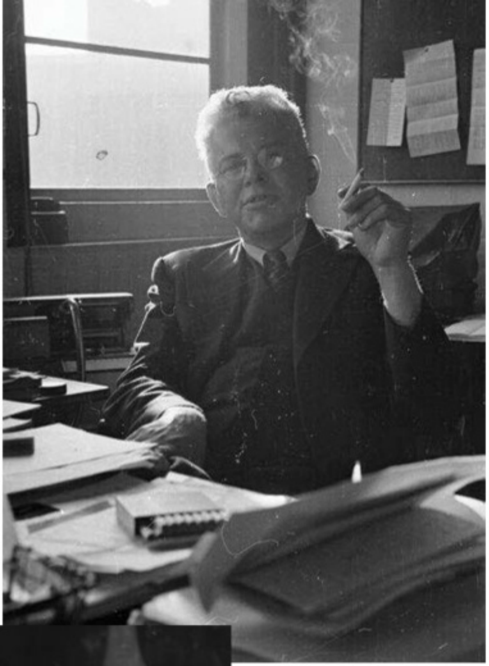
Biochemist Norman Heatley developed a method of purifying penicillin.

Boot's workshop skills were now put to the test. He did not let Randall down. Oliphant's interest might have been piqued, but he was by no means convinced about the likelihood of success. While he provided all the resources he could spare for them to build the prototype, Randall and Boot had to beg, borrow and steal the rest.

Slowly, their creation came into being. When a metal disk was needed to plug one end of the primitive apparatus, Boot used a halfpenny. Joints were crudely sealed with wax. A Birmingham scrap-metal yard soon became their most important supplier. It was a time of scarcity, but they found a way. With its echoes of 'string and sealing wax' improvisation, Ernest Rutherford would surely have approved. The war had made an old man's penny-pinching prejudice everyone's necessity.

By February 1940, after months of intense

FRANCIS REISS/PICTURE POST/HULTON ARCHIVE/GETTY IMAGES; WIKIPEDIA COMMONS



Oliphant (top right, in his office at Birmingham University in 1945) and Florey (above, after receiving the Albert Gold Medal in 1946) led teams that over a period of 100 days in early 1940 developed the device that was critical to winning the war – microwave radar – conceived the powerful weapon that ended it – the atomic bomb – and produced the miracle treatment that enabled countless casualties to survive it – the first ever antibiotic, penicillin.

They are the two most consequential Australians of the war, and among the war's most consequential scientists.

FRANCIS REISS/PICTURE POST/HULTON ARCHIVE/GETTY IMAGES; DEAGOSTINI/GETTY IMAGES; HUTLON-DEUTSCH COLLECTION/CORBIS/CORBIS VIA GETTY IMAGES

work, Randall and Boot were ready to test the first model of their cavity magnetron. It resembled a small engine rotor, with a series of cylindrical holes cut into it and was crafted from a solid block of copper attached to an untidy tangle of tubes and pumps. A car headlamp was connected to demonstrate the output of power.

On the morning of 21 February, with the flick of a switch, the cavity magnetron burst into life and the headlamp shone spectacularly. While the original simple magnetrons could barely power a light bulb, the new resonant cavity magnetron was soon producing so much power it burned out headlamps and lit cigarettes. Oliphant, who joined the excited group within half an hour of the switch being flicked, quickly ordered the headlamp replaced with hardier fluorescent tubes. They too lit up the room – as well as the spirits of Randall, Boot and Oliphant.

On 24 February, Boot confirmed with a scrawl in his black laboratory notebook that the radio wavelength produced by the resonant cavity magnetron was 9.5 centimetres – almost exactly what the Royal Air Force needed for the next generation of portable, all-seeing microwave radar. Power output was soon confirmed at an extraordinary 400 watts – ten times better than any previous magnetron. And while 400 watts appeared to be the ceiling for the klystron, for the cavity magnetron it was just the beginning.

The two young scientists always credited Oliphant's "great drive" for the success of the entire unlikely enterprise. It was, they reflected years later, "fortunate ... that we were in Oliphant's laboratory at the University of Birmingham".

Oliphant was project manager, mentor, fundraiser and problem solver. Not a natural diplomat, he nevertheless reached out to those who might help and provided his team with the necessary resources. Always available, always questioning, if not always right, Oliphant inspired and lifted his staff to achieve ends that just six months before were pie in the sky. He was an internationally renowned scientist in his own right, but, just as importantly, a talented science administrator, with a keen eye for fresh talent and the ability – as well as the dogged persistence – to make things happen even under the most challenging conditions.

THE FEATS OF IMPROVISATION and ingenuity playing out in Oliphant's lab were being replicated 90 kilometres south in Oxford, where another scientist in his 20s was being forced to use old bathtubs, bedpans, food tins and milk churns to grow penicillin mould. 'At one period the ordinary empty soft drink bottle became a prized possession,' the British biochemist, Norman Heatley, later recalled.

At this early stage of the penicillin project, Heatley's job was critical. Sir Henry Harris, an Australian who succeeded Florey as head of the Dunn School, put it this way: 'Without Fleming, no Chain or Florey; without Chain, no Florey; without Florey, no Heatley; without Heatley, no penicillin.' If Heatley could not grow enough mould, Chain would have nothing to extract and purify, and Florey nothing to test.

When Britain declared war on Germany, Florey was finalising his first major funding proposal to pursue penicillin research. He had thrown his lot in with the mysterious mould and went all out to impress the Medical Research Council and its Secretary (and former colleague at the University of Sheffield) Sir Edward Mellanby. Pending a full examination of his proposal by the Council, Mellanby forwarded £25 "for expenses". Under a separate grant, German-born Ernst Boris Chain was also awarded £300 with £100 for expenses per annum for three years – thus, if nothing else, providing him with security of employment.

So, with £25 and a dash of hope, a revolution in human healing began. It was a start, but it was nowhere near enough. And Florey, like so many research scientists before and since, grew sick of the endless rounds of funding applications and increasingly self-conscious of his emerging status as an "academic highway robber". But the powerful team he assembled could do little without the necessary equipment and

The two young scientists always credited Oliphant's "great drive" for the success of the unlikely enterprise... Oliphant was project manager, mentor, fundraiser and problem solver.

materials.

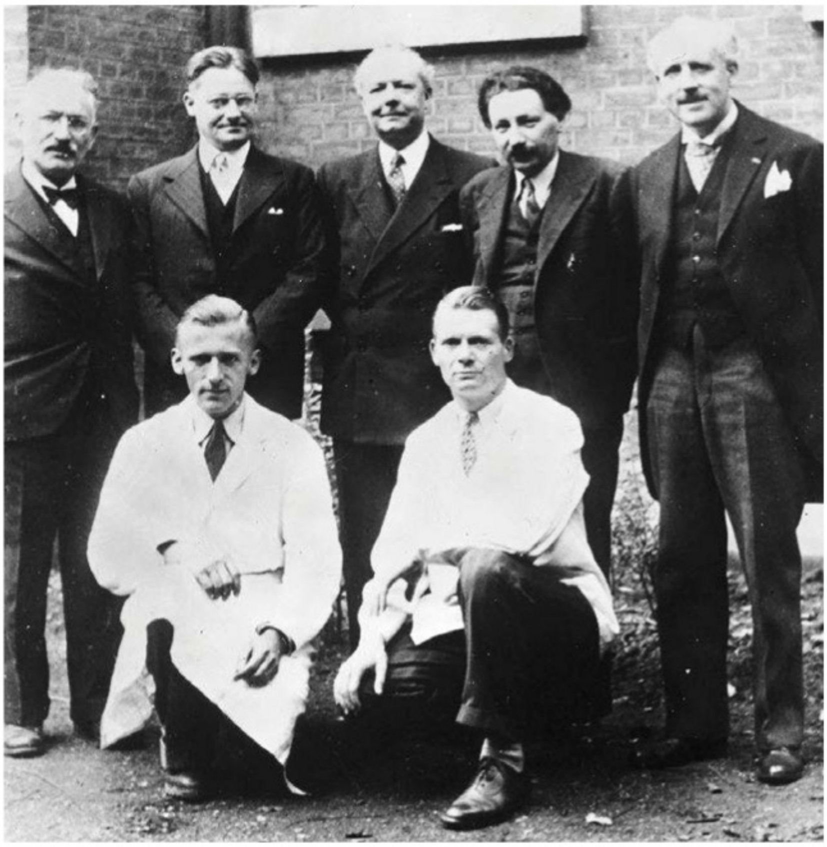
Salvation came in the person of Harry M 'Dusty' Miller, one of the Rockefeller Foundation's representatives in Europe. On 1 November 1939, the globe-trotting Miller was in Oxford, having lunch with the university's Vice Chancellor, Professor George Gordon, and his family. For an American with money, no doors were closed. Dusty Miller, an early scout for an ascending America, embodied the changing fortunes of Anglo-American relations.

After lunch, Miller dropped in to see Florey at the Dunn School. He found the lab "quite full" with evacuees from the Ministry of Health in London, but other than that, his timing could not have been better.

The straight-talking Florey mentioned to Miller, a trained bacteriologist, that he was "just on the point" of asking the Rockefeller Foundation for a grant to support research he was beginning on "naturally produced bacteriological inhibitors".

Miller's ears pricked with interest. He respected Florey, noting in a memorandum sent a few days later to the Rockefeller Foundation headquarters in New York that the young Australian is "practically the only experimental pathologist of any real distinction in the British Isles". Miller added that Florey "has the full confidence of Mellanby".

Miller's initial enthusiasm paved the way for Florey and Chain's formal application to the foundation a couple of weeks later, on 20 November. If approved, it would single-handedly take care of all the money woes and save Florey from the distraction of constant fundraising. With so much riding on its success, Florey ended his application letter with a new, if characteristically understated, appreciation for practical outcomes, something much favoured by the business-like Americans: "It may also be pointed out that the work proposed, in addition to its theoretical importance, may have practical value for therapeutic purposes".



On 19 February – two days before Randall and Boot successfully demonstrated their cavity magnetron to Oliphant in Birmingham – Florey and Chain learned that their application had been successful. They received £1250 (or US$5000), guaranteed for a year, but eventually extended to five.

The work began in earnest. Florey's claim to Mellanby that penicillin could be easily produced in large amounts would now haunt Heatley. Heatley developed a test to measure the potency of each batch. He tried many different recipes for the broth to grow penicillin mould, aiming always to produce more of it and of a higher potency. Sugars, salts, malts, meats and alcohol were all thrown in. Heatley even tried brewer's yeast and Marmite, the ghastly tar-like black sandwich spread much beloved by the English at breakfast. It was a messy, smelly, thankless task.

And frustrating. The problem of finding the optimal growth medium was one thing, but a more prosaic lack of laboratory space and suitable vessels also restricted production and the quantities remained small. On top of this, extracting penicillin

KEYSTONE/HULTON ARCHIVE/GETTY IMAGES; NATIONAL SCIENCE MUSEUM; PA IMAGES VIA GETTY IMAGES

Cavity magnetron developers (opposite top) Harry Boot, centre, and John Randall, at right, shown here in 1959, built the first practical device (right) that produced the microwaves needed for radar. The multi-tube design (below centre) was the thing that made the difference. After they'd conceived it, "Randall started to scratch a design on the back of an envelope while Boot did the calculations to create the first hazy sketch of arguably the most consequential invention of the Second World War."

from the mould was extraordinarily difficult. Initially, ether was the only solvent known to filter out penicillin from the mould, but the penicillin disappeared when it was removed from the ether. This vanishing trick had confounded and defeated Fleming and his successors. Chain, fascinated by penicillin's instability, threw himself at the problem. He developed techniques of stabilising penicillin at certain pH (acidity) levels and extracting it at just above freezing. Even so, it took hundreds of litres of mould filtrate to produce only minute quantities of penicillin itself.

The first critical breakthrough in logistics came on 18 March 1940. Heatley called his new method "reverse extraction". Building on previous practice, it used ether to extract penicillin from the mould (at Chain's suggestion amyl acetate soon replaced ether and proved a better and safer solvent) and then dissolved it in water. At last, Chain now had enough material to play with and purify. But he never forgave Heatley for succeeding where he had failed.

Assisted by Edward Abraham, another young biochemist who joined the team in November 1939, production, extraction and purification proceeded in leaps and bounds. Abraham contributed a newly discovered technique of alumina column chromatography, which greatly assisted in removing impurities, and Chain, using another recently discovered technology – freeze-drying – was able store the penicillin without sacrificing its potency. After weeks of work, Chain held a test tube with a few pinches of a dusty brown powder – penicillin's first face to the world.

Chain was keen to start testing penicillin on animals to determine its toxicity. He had already diluted a milligram of the brown powder in a litre of distilled water to discover it inhibited the growth of staphylococci bacteria. With such high potency, Chain would not have been surprised if penicillin proved toxic to laboratory mice. Busy with other responsibilities across the Dunn School, and with their relationship increasingly strained, Florey fobbed off Chain's immediate urgings. Chain proceeded undeterred.

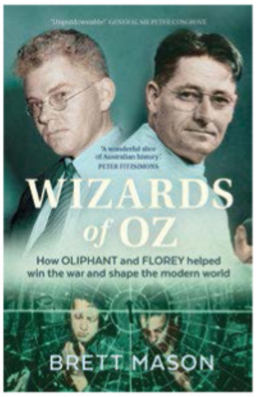
The following day, without obtaining Florey's permission, Chain asked his colleague, Dr John Barnes, to inject about 40 milligrams of the brown penicillin powder mixed with a small quantity of water into the abdominal linings of two mice. Chain waited for any signs of distress from the rodents. After several hours, to his great delight, the mice showed no ill effects. Penicillin was not toxic.

Chain would later claim this experiment was "the crucial day in the whole development of penicillin and the day on which everything became possible to us". Not quite. Fleming had already shown in 1929 that penicillin was not dangerous to a mouse and a rabbit. Meanwhile, miffed that Chain went ahead with the experiment in his absence, Florey repeated it himself by injecting the tail vein of a mouse. By chance, the mouse urinated soon after. It was brown, the colour of the powder. With not a moment to miss, Florey took a drop of the rodent's urine and deposited it on a bacterial culture in a Petri dish. The urine soon killed the germs, proving that penicillin's antibacterial effect was not affected as it passed thought the mouse's body.

The next question would go to the crux of their research project: what if the mouse injected with penicillin happened to be suffering from a bacterial infection? The mouse would not be harmed, this much seemed certain, but would the bacteria?

A revolution in healing, slowly inching ahead over the course of millennia, was now breaking into a sprint. ◉

The Oxford penicillin team of Florey (opposite, standing second from left) and Chain, standing second from right, wasn't always harmonious, but between 1937 and 1940 it developed a successful – if rather inefficient – method of producing pure penicillin. Industrial-scale production came after Florey enlisted help in the US in 1941.


'Unputdownable' GENERAL SIR PETER COSGROVE
'A wonderful slice of Australian history' PETER FITZSIMONS
WIZARDS of OZ
How OLIPHANT and FLOREY helped win the war and shape the modern world
BRETT MASON

This is an edited extract from: *Wizards of Oz: How Oliphant and Florey helped win the war and shape the modern world*, by Brett Mason. Published by NewSouth books and available now (rrp: $34.99).

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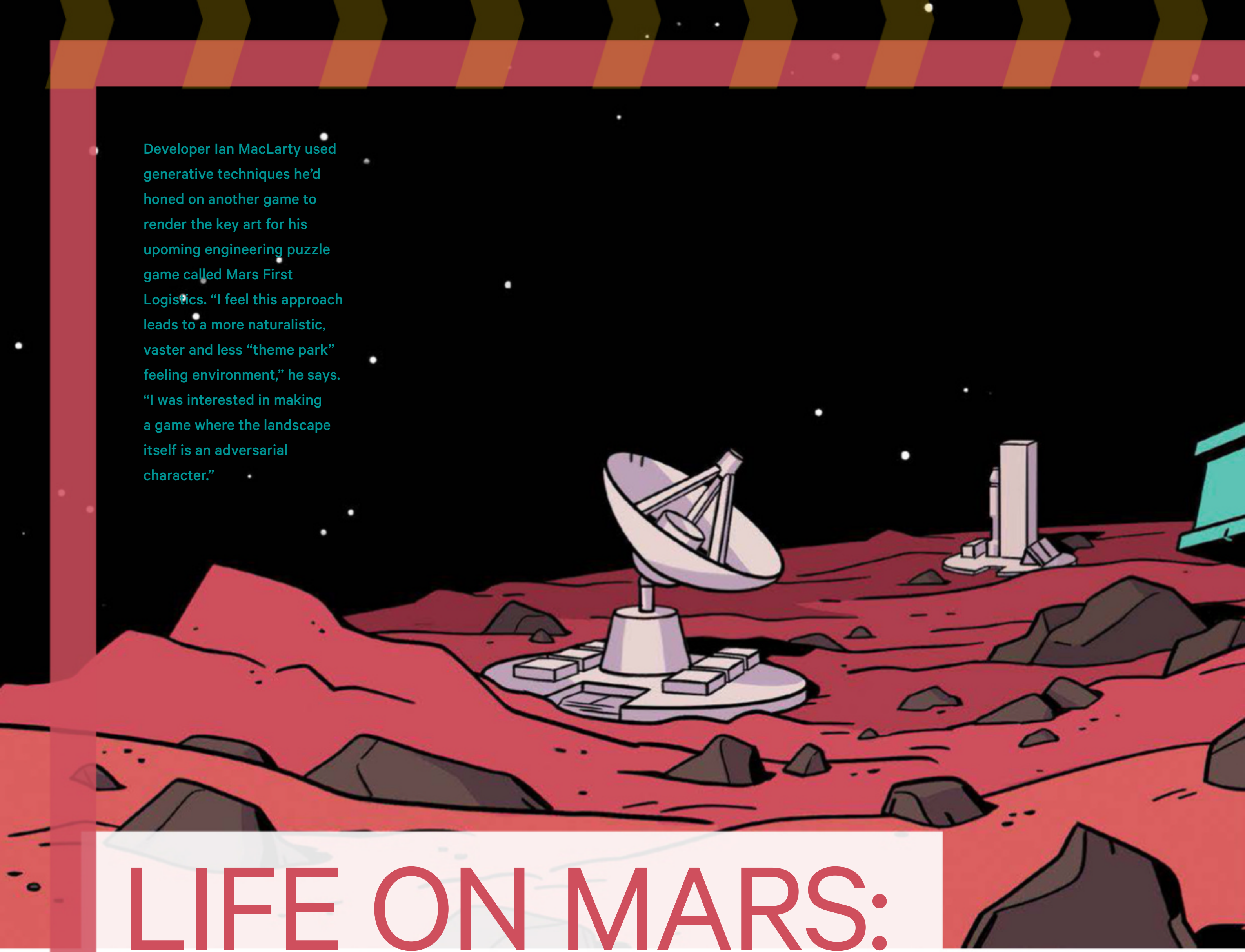


Developer Ian MacLarty used generative techniques he'd honed on another game to render the key art for his upoming engineering puzzle game called Mars First Logistics. "I feel this approach leads to a more naturalistic, vaster and less "theme park" feeling environment," he says. "I was interested in making a game where the landscape itself is an adversarial character."

LIFE ON MARS:

EXPLORING THE RED PLANET UP CLOSE AND PERSONAL

Sure, as they say: it's just a game. But as **PETRA STOCK** discovered, the current crop of virtual reality games about Mars are informed by real science and real data – and there's no reason why a player won't be among the first Mars colonists in future decades.

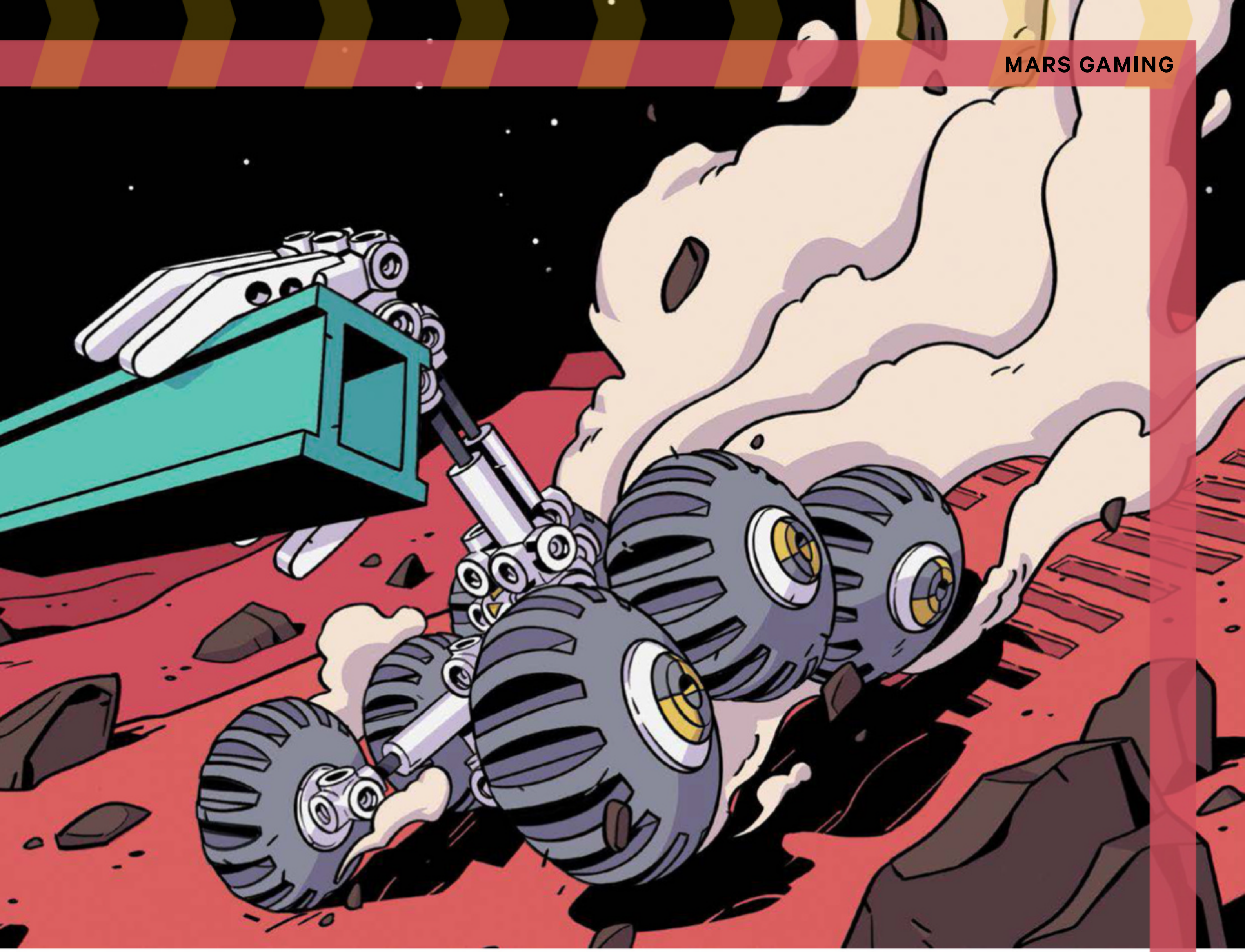
I'm hovering 10 metres above the surface of Mars, piloting Ingenuity – a tissue-box-sized helicopter – as it skitters and soars overs the rippled surface of Jezero Crater. Delicately engineered carbon fibre blades gently whir, barely audible against my imposing orchestral soundtrack.

Looking ahead, outcrops and crater cliffs dot the sparse, windblown landscape. Dusty reds and burnt umbers stretch out towards the horizon.

I'm not wearing a spacesuit, more than 90 million kilometres from Earth. Instead, I'm wedged in the study nook of a terrace house in Melbourne, where the most uncomfortable part of my outfit is the virtual reality headset that's plugged into a laptop. But as I guide the tiny spacecraft, alone in the expansive, unearthly vista of Mars, I feel a long way from home.

THE 3D PATH TO MARTIAN LEARNING

By the time Perseverance's carefully packed dronecopter, Ingenuity, took its first flight on 19 April 2021, gamers had been exploring the Martian surface for months. Mars Flight VR, a flight simulator by



MARS FIRST LOGISTICS KEY ART/IAN MACLARTY/SHAPE SHOP

Melbourne video game developer Conor O'Kane, allows players to use the small, solar-powered helicopter to explore the neighbourhood of Jezero Crater, landing site for the rover, Perseverance.

With controller in hand, players steer the ruler-length helicopter, nicknamed Ginny, over the planet's landscape, sometimes completing science missions, including taking photographs of selected sites.

Experiencing Mars in virtual reality eclipses two-dimensional video or photos, says O'Kane. Immersed in 3D, players can better appreciate the planet's topology, gaining a sense of distance and scale. "You can see, oh, we're going to land here," O'Kane says. "And it's only a couple of hundred metres to the hills. You can see how high the hills are.

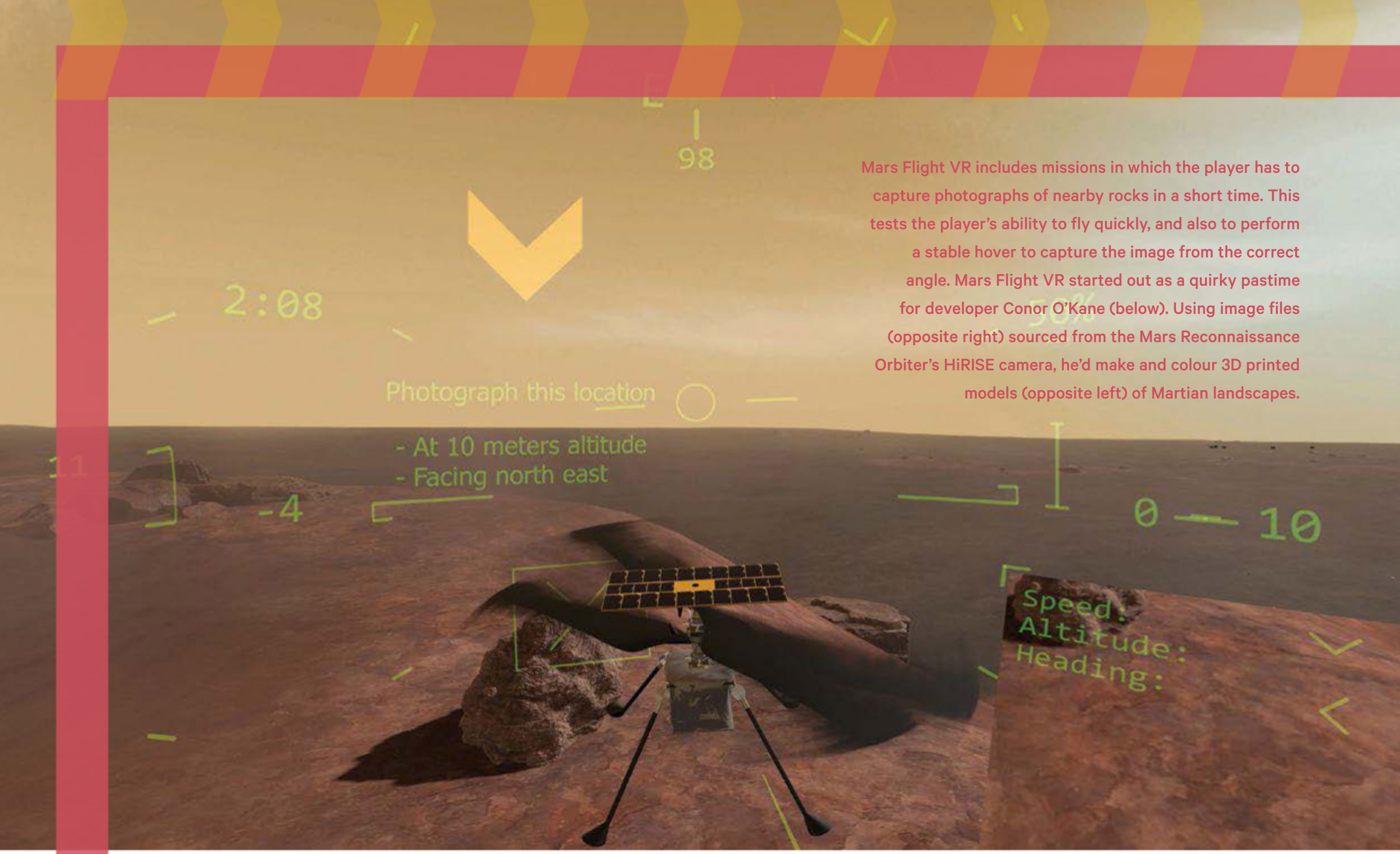
"My hope is that people will start to think, 'why are there hills like this on Mars?' And then they'll read a bit about it. And they'll learn, actually these hills are not just hills, they're a river delta deposited by a river flowing for millions of years."

Video games might seem an escapist distraction, but O'Kane thinks they have huge potential as a vehicle for science advocacy. By presenting people with a simulator that makes Mars seem real, he believes a new generation will be inspired to learn more about science and planetary exploration.

They're grand aims to grow from what started as a quirky hobby. Six years ago, O'Kane began home-making sections of the Martian landscape. Starting with digital terrain data from the High Resolution Imaging Science Experiment – HiRISE – he used a home 3D printer to replicate slices of Martian landscape in 1:20,000 scale before painting them in colourful acrylics.

"So I had been getting into this … then I thought I could take the landing site for this new mission, Perseverance … and fly around it in VR before the helicopter even gets there."

Professionally, O'Kane has worked as a video games developer and technical artist for more than two decades. Relying on his knowledge of programming and 3D printing, he imported the Mars terrain data into the Unity video game engine and began to bring it to life in virtual reality.



Mars Flight VR includes missions in which the player has to capture photographs of nearby rocks in a short time. This tests the player's ability to fly quickly, and also to perform a stable hover to capture the image from the correct angle. Mars Flight VR started out as a quirky pastime for developer Conor O'Kane (below). Using image files (opposite right) sourced from the Mars Reconnaissance Orbiter's HiRISE camera, he'd make and colour 3D printed models (opposite left) of Martian landscapes.

Mars Flight VR is free to download and play: scan below if you want to take Ingenuity for a tour.

Aiming for accuracy, in 2018 he toted a VR headset, laptop and game demo to the Mars Society Convention in Los Angeles with funding assistance from Film Victoria. There, he met people from NASA – even some working on the Perseverance mission – and other engineers interested in space flight, who provided feedback on details like the atmospheric density on Mars, and the properties of the helicopter.

"Of course, the real helicopter flies itself, you don't directly control it, you just give it a destination and it flies. But that's no fun in video games," O'Kane says. "So, I tried to make it feel as much like flying on Mars as I can while still being accessible."

LPL: OPEN ACCESS LAB

Known for its deserts and canyons, the US state of Arizona is home to a research lab which has been photographing the Red Planet in high resolution detail since 2006.

The University of Arizona's Lunar and Planetary Laboratory (LPL) operates HiRISE, the powerful camera onboard the Mars Reconnaissance Orbiter.

So far, HiRISE has captured around 4% of the Mars surface. Images of the planet are acquired from orbit by a powerful camera, relayed through deep space networks and then processed by LPL into digital topography models of the Martian landscape.

The images and data play an important scientific role, helping to reveal the planet's environmental history and its geological processes. One research project used the data to look at how carbon dioxide sublimates, changing phase between ice and vapour, and is the driving force behind erosion and change on the planet.

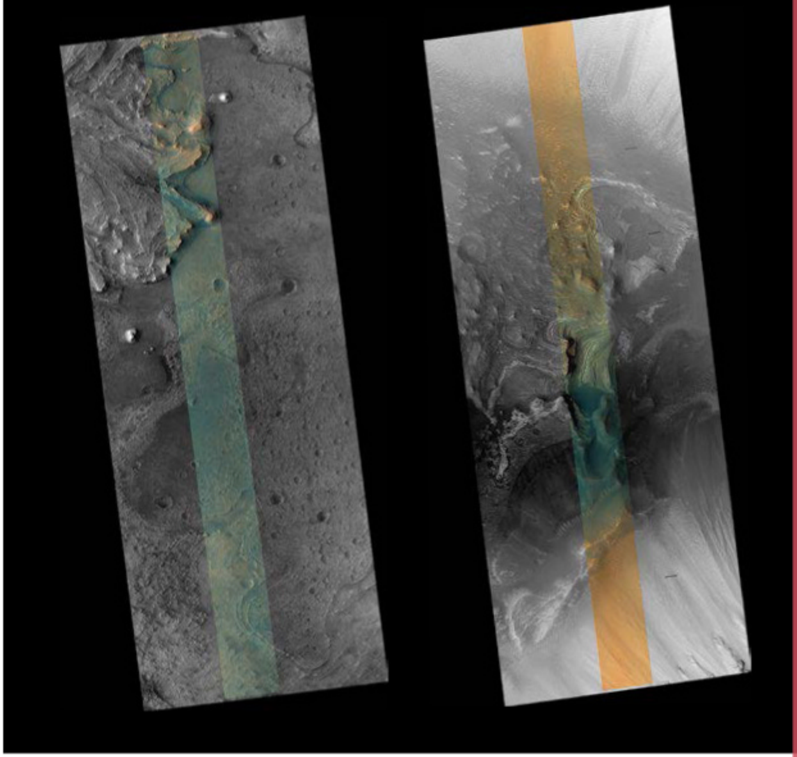
HiRISE research scientist Dr Matthew Chojnacki says, "a lot of the gully activity for example, is largely, we think, driven by carbon dioxide processes, its phase change … How it occurs and travels from one side of the planet to the other, and accumulates in these darker, colder local regions."

Yet, far from being exclusive or out-of-reach, HiRISE is "the people's camera".

LPL's commitment to public outreach sees Mars images and data released on a monthly basis; much faster than other NASA programs.

"We release new data as soon as we can get it calibrated and processed," says Dr Sarah Sutton,

LEFT AND ABOVE: CONOR O'KANE / MARS FLIGHT VR



LEFT: CONOR O'KANE. RIGHT: HIRISE

a photogrammetry and image processing scientist with the HiRISE Operations Center.

"We're always thrilled when the public engages with the data."

Engagement is so intrinsic to LPL's approach that members of the public can even nominate locations on Mars to be photographed, using a tool called HiWISH.

"It's easy, and it's fun," says Sutton. "And it's very exciting when your target gets acquired."

While there's no guarantees a publicly requested site will be captured, many are. In fact, Sutton says it was a request through HiWISH that confirmed the final landing site of UK's Beagle 2 Mars Lander, which was due to land on 25 December 2003, but declared lost after an extensive search.

"It did actually land," she says. "It was thought that it crashed. But they found it because they could actually see it in our images, and nobody had looked.

"From the analysis of our HiRISE images, they were able to determine then that the Beagle had landed and that some of its panels had opened, but not fully. And so, it was never able to communicate back." LPL's website, called 'Made with HiRISE' showcases the broad range of artistic and technological interpretations of Mars data and images; everything from visual arts, to music, school projects, animations, apps and augmented reality.

LPL has even produced tools allowing its digital terrain models to be exported for uses like 3D printing, and actively encourages creative exploration of its data and images, by artists, designers ... and video games developers.

It's a way of reimagining real Mars, evoking an outer space sensory experience rendered through virtual colour, texture, depth and sound.

ROVERS IN REAL LIFE

Rover planning on the Red Planet can seem a bit like a video game sometimes, says NASA program scientist Dr Mitch Schulte.

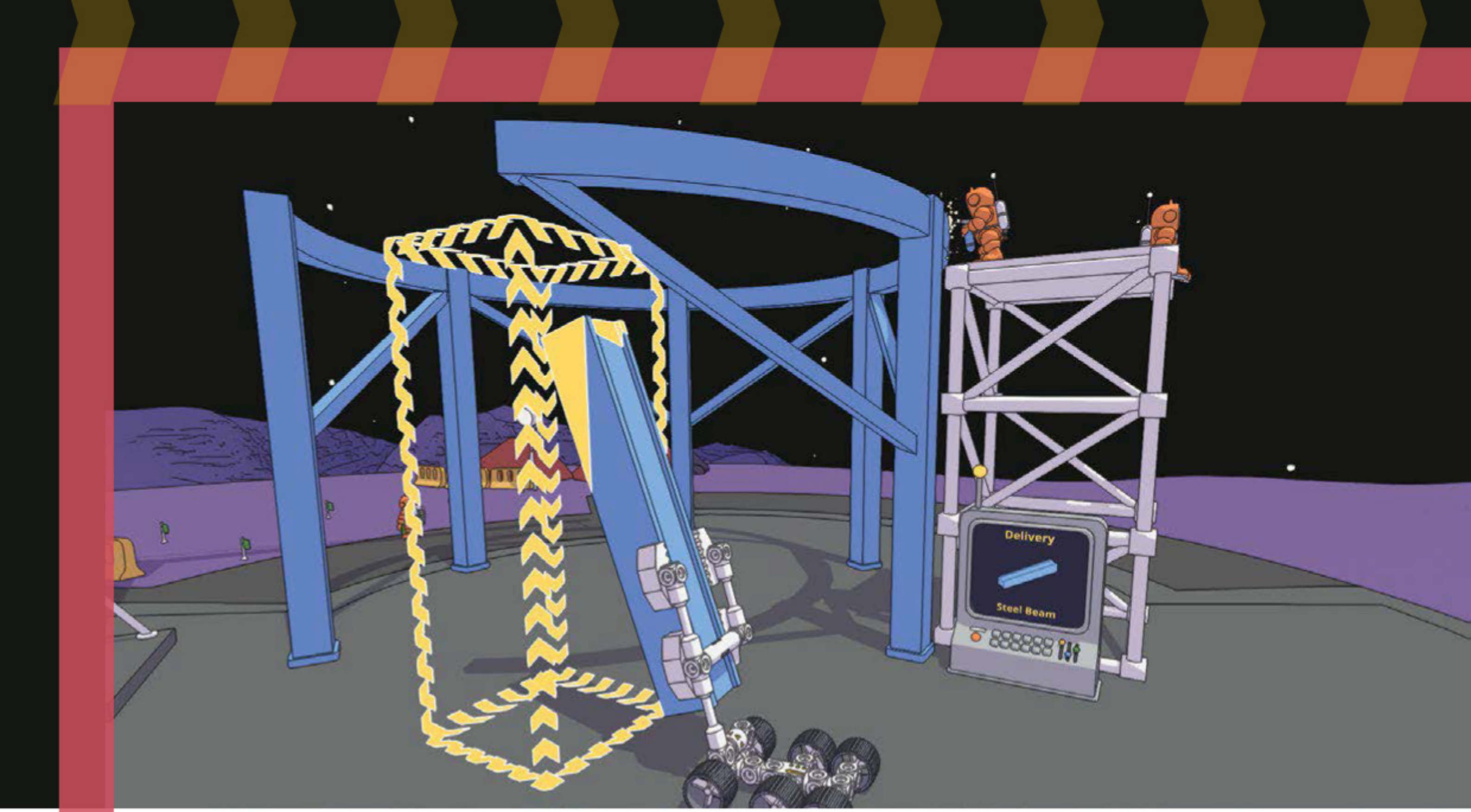
Schulte is based in Washington, DC and oversees the science goals of Mars missions – like those involving Perseverance and Ingenuity. His role includes assessing research proposals to access NASA's vast public archive, called the planetary data system.

A rover like Perseverance can't be controlled in real time, he says. Mars is simply too far away, so everything needs to be planned in advance.

That's why, Schulte says, "coding is everything".

"The amount of debugging that goes into the software ahead of time is enormous, because we can't afford any mistakes. And now when we want to tell the rover even just to drive 20 metres over to that rock, that is pre-programmed. That command is sent from Earth, directly to the rover, to its antenna. And then it performs those functions based on the software and the rover computing elements that are onboard."

More recently they've added an 'auto navigation' capability. It's programming that enables the rover



IT'S THE KIND OF MAKE-BELIEVE THAT MAKES THE POSSIBILITY OF MARS TANGIBLE, EVEN DOMESTIC

to use its cameras to avoid major obstacles, like cliffs and sand dunes, which it encounters along its route. In fact, you can do this too: NASA's website includes a simple game that lets you code commands to complete Ingenuity missions, though – sadly – not for real.

Schulte might be "knee deep in the science" of Mars exploration, but he says public engagement is an important part of NASA's mission. Being government funded, the space agency is keen to ensure the public comes along for the ride.

"We want to make sure they understand what we're doing, and why we're doing it. What they're getting out of it, what the scientific community gets out of it," he says.

Schulte believes that sparking an interest in the science of Mars – even tangentially through a video game – is definitely worth it. He sees an interplay between exploring Mars through a medium like art or video games, and growing awareness about the science, technology and engineering aspects of the actual missions.

Playing a game set on Mars might lead people to question, 'Oh, what's it like outside on Mars?', he says. "And then of course, that leads them to us."

SPECIAL DELIVERY: ON MARS

I'm back on Mars again, but this time the landscape looks different. Here, like a 1950s cartoon drawn in ligne claire, the saturated reds and purples of the planetary surface are contained within clear black outlines. An upbeat, electronic soundtrack sets me buzzing as I snap together parts – a connector, servo and claw – to customise my Mars rover.

Levering the vehicle's new and awkwardly constructed arm under an upturned crate, I hoist it off the ground and set off towards the greenhouse, tyres crunching regolith and kicking up Martian dust.

Contract complete!

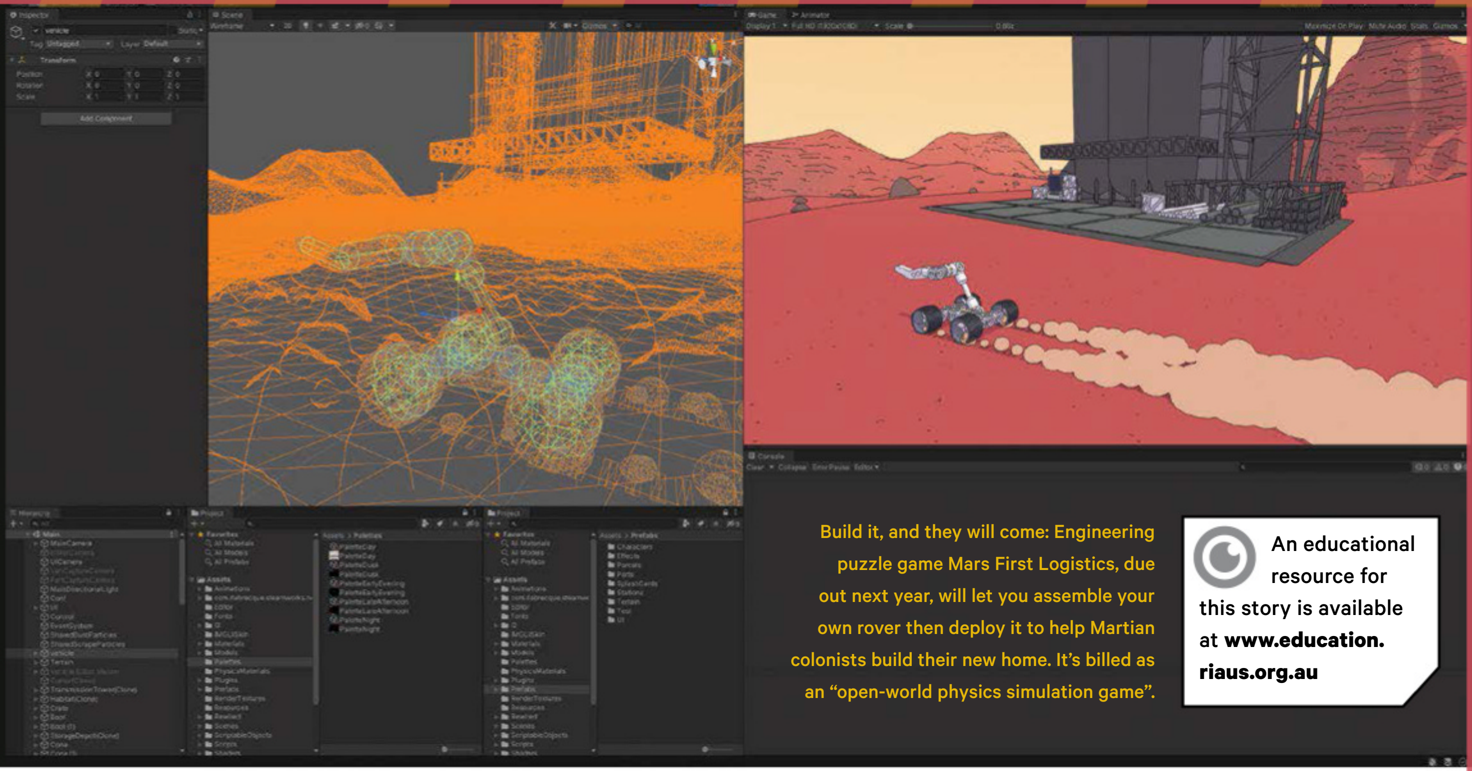
Engineering puzzle game Mars First Logistics is due for release in early 2023, with a demo available on the Steam platform.

In a more artistic than authentic aesthetic, players in this game complete delivery contracts, providing logistics support for the construction of a Mars colony (a goal private company SpaceX aims to achieve by 2050). It's Mars, Jim, but not as we know it.

"I wanted to make it so it feels like you're playing with Lego, like you're playing with a toy," says developer Ian MacLarty, who created the game with his team at Shape Shop. "But it's still trying to bring out that engineering kind of ingenuity."

Pieces can be deployed flexibly in interesting and surprising ways, both mechanically and aesthetically. "So for example, I've got a thing called the hydraulic

MARS FIRST LOGISTICS / IAN MACLARTY/SHAPE SHOP



Build it, and they will come: Engineering puzzle game Mars First Logistics, due out next year, will let you assemble your own rover then deploy it to help Martian colonists build their new home. It's billed as an "open-world physics simulation game".

An educational resource for this story is available at **www.education.riaus.org.au**

cylinder, which gives you linear motion," MacLarty says. "And then I've got a servo, which gives you rotational motion. And just those two things combined, you can do so much."

The game manages to bring a touch of the everyday to the far, far away. While some delivery missions might involve construction materials – a steel beam or a telescope mirror – for building a greenhouse or an observatory, in others, players find themselves delivering lunch to the working astronauts.

It's the kind of make-believe that makes the possibility of Mars tangible, even domestic – the household to-do list of humans 2.0.

VIRTUAL REALITY GETS REAL

After years in development, Mars Flight VR was released for early access in June 2020 as a second wave of the COVID-19 pandemic locked down O'Kane's home in Melbourne, Victoria. A month later, NASA's Perseverance rover was launched.

O'Kane, who now works as a simulation engineer at space tech company Saber Astronautics, was glued to the mission – watching NASA's livestream and updates by the Mars Guy (aka Mars geologist Dr Steve Ruff) on YouTube. When the rover landed on 18 February 2021, it came as a huge relief.

"And then amazingly enough, the helicopter, which they expected to fly for like six minutes and then break, is still going 18 months later."

The helicopter has clocked up more than 30 flights, covering more than 7.3 kilometres, taking hundreds of photos of the Martian surface, according to NASA. O'Kane's simulator has been downloaded more than 10,000 times.

Now the Martian landscape is taking on new, human, dimensions.

"I've been flying around this for a couple of years, getting to know the area, getting to know the hills. And as the rover team drive to different locations, they name it," he says. "There's this particular outcrop, kind of a butte, or a hill. They've called it the Kodiak outcrop. I used to fly around that."

Scientist, science-fiction author and space enthusiast, Arthur C Clarke wrote that "the astronomical artist will always be far ahead of the explorer. They can depict scenes that no human eye will ever see, because of their danger, or their remoteness in time and space".

Just as books, art and film brought the Moon landing to life long before 1969; today video games and virtual reality offer the chance to play, fly and deliver things on the Red Planet, decades before crewed missions take flight, but as space agencies explore the planet with cameras, rovers and drone-copters, searching out signs of life and preparing for the possibility of human exploration before 2050.

One of Earth's first Martian colonists could be skittering and soaring Ingenuity above Jezero Crater, right here, right now, in a bedroom not far from you. Their virtual reality, not knowing that it's becoming real. ◉

PETRA STOCK is based in Melbourne. Last issue, she interviewed David Popa for the gallery: *Here today…*

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Sean Connery's James Bond – resting here in a scene from 1964's *Goldfinger* – filled the screen with iconic moments, by air, land and sea. Over the years, Bond's many scriptwriters have employed technology on the horizon of what was possible.

MICHAEL OCHS ARCHIVES / GETTY IMAGES

ZEITGEIST

SCIENCE MEETS LIFE

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BOND: REEL TO REAL
007 is synonymous with style, spectacle and spy-fi gadgets – some of which have come true

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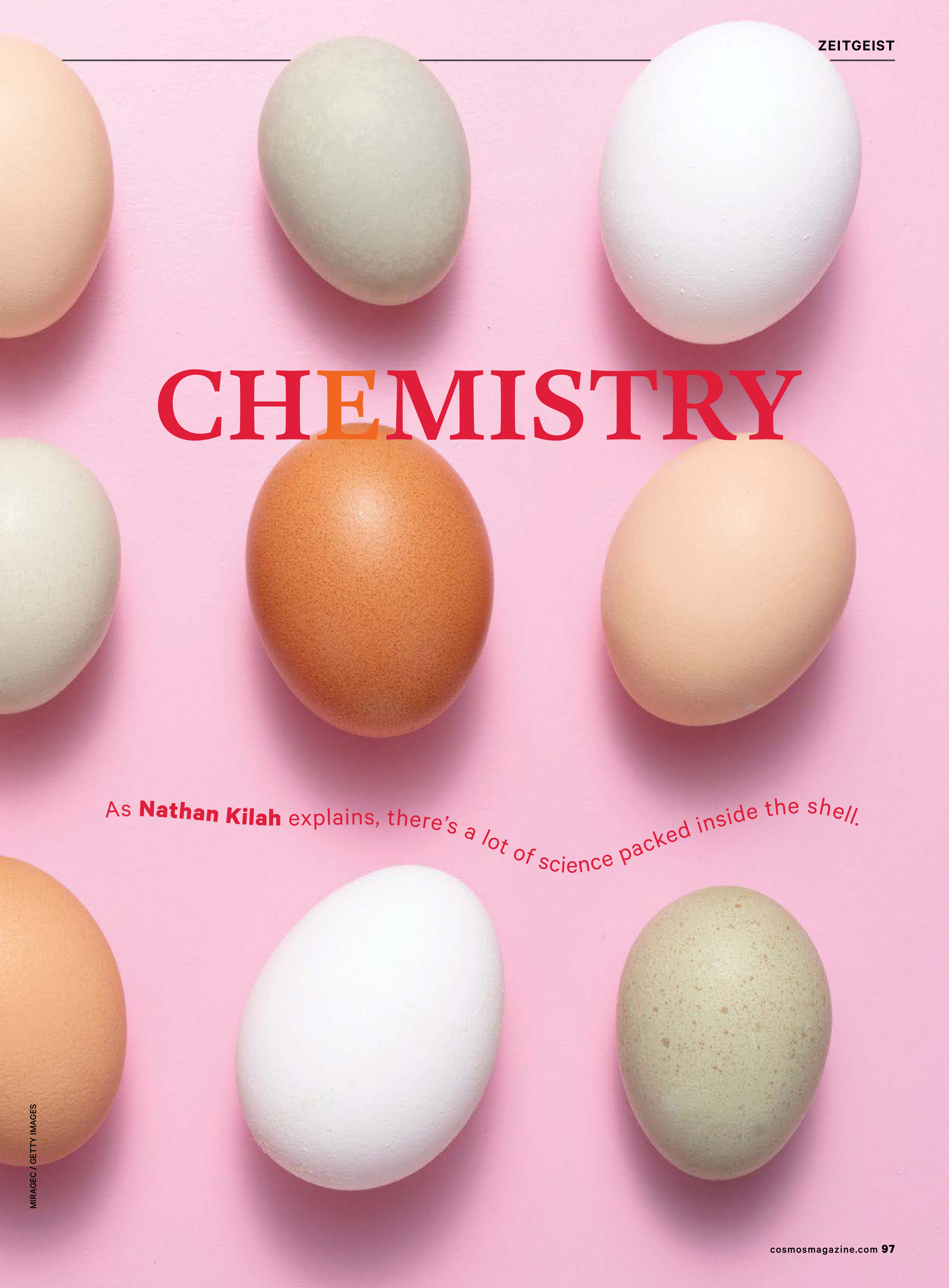
EGGSCELLENT

They’re an everyday miracle of chemistry, and delicious into the bargain.



CHEMISTRY

As **Nathan Kilah** explains, there's a lot of science packed inside the shell.

MIRAGEC / GETTY IMAGES

There are few foods as versatile as the humble egg. These nutrient-filled packages are excellent scrambled, poached, or fried, and are essential in cakes, puddings, soufflé, quiche, ice creams, sauces, drinks, cosmetics, vaccines and more. But what is it about the humble egg that makes it such an adaptable ingredient and scientifically useful object?

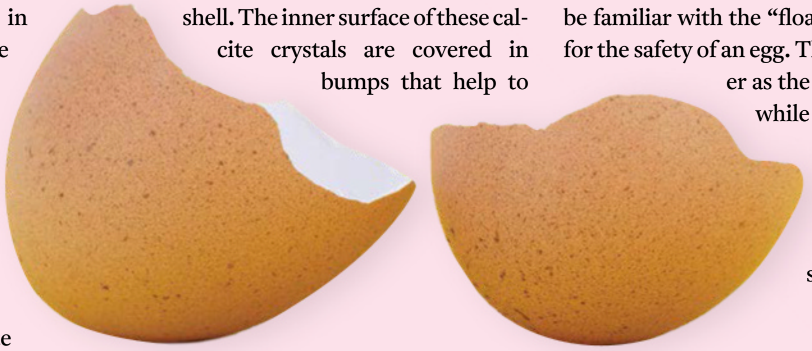
Chicken or egg?

First thing first: the egg definitely came first. The emergence of amniote eggs some 330 million years ago marked a significant evolutionary development as both the water and nutrients were available in the one package. This broadened the possible habitat of egg-laying creatures to varied terrestrial environments. Chickens are relatively recent, evolving around 60,000 years ago and were only domesticated 3000 years ago. The complexity and efficiency of the egg can't be understated: the developing chick makes excellent use of the contents, especially as there is no way for wastes (other than carbon dioxide) to escape the shell.

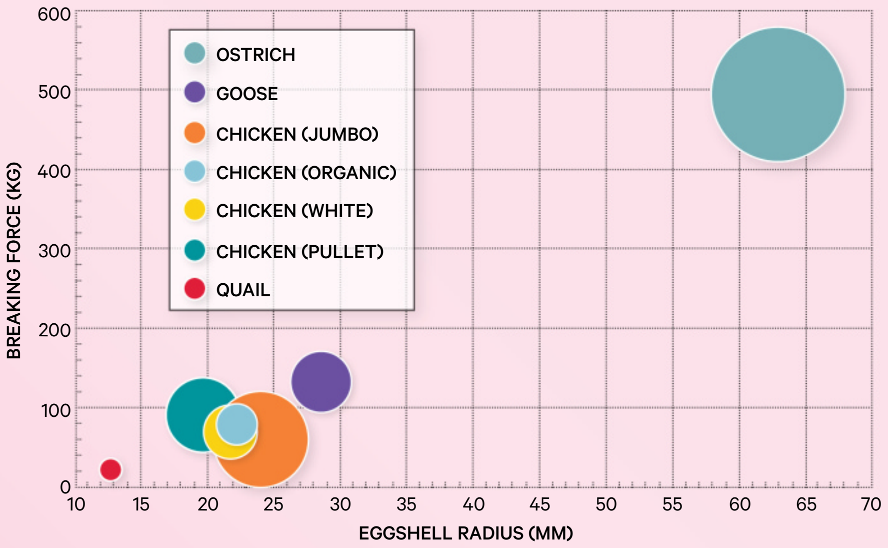
Let's get cracking

The egg shell is primarily made of the calcium carbonate mineral calcite, bound and shaped by the inclusion of proteins and sugars. The combination of inorganic crystals and organic proteins give incredible microstructural and mechanical strength to protect the embryo from physical damage.

The surface of the egg is covered with a very thin layer of proteins, which keep bacteria outside the shell while allowing gases to permeate through thousands of surface pores. These pores run through vertically aligned crystals that make up the shell. The inner surface of these calcite crystals are covered in bumps that help to connect the shell to the two membrane layers inside. The membrane is lifted off the shell at the air cell (or space), and you might be familiar with the "float test" as a marker for the safety of an egg. The air cell gets larger as the egg dehydrates, so while this test will help you tell a new egg from an older egg, it doesn't indicate bacterial spoilage. In fact,

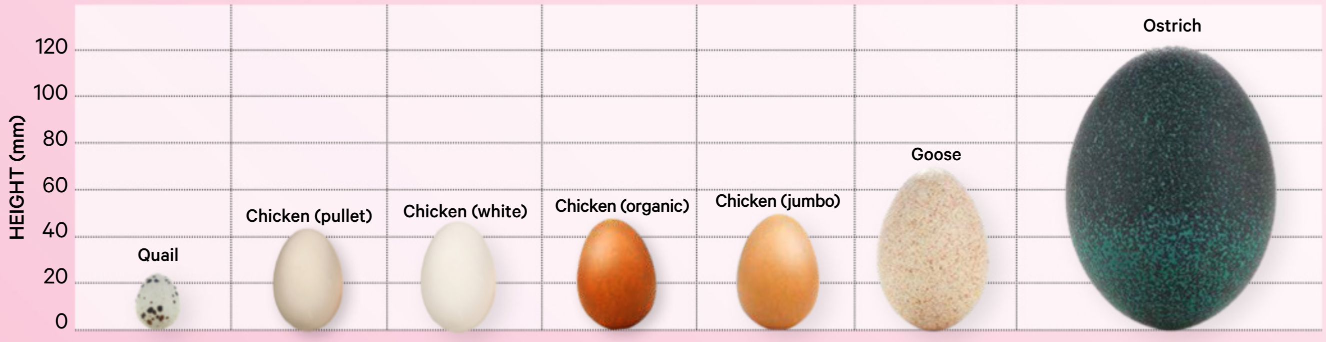


STURDY CAPSULE It takes a fair bit of force to break an egg



Here, normal force at failure (breaking point) is shown as a function of eggshell radius. Each circle is centred on the mean breaking force and the radius is proportional to the standard deviation for each given type of egg. The force increases with egg size.

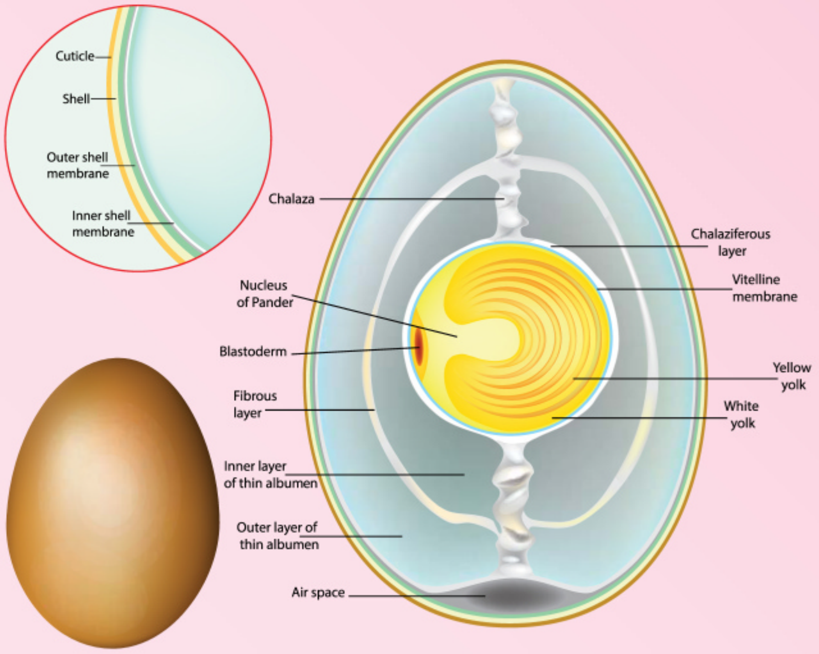
EMBRYONIC ENVELOPES It's a simple equation: the bigger the bird, the bigger the egg



Egg species in order of increasing height/volume: quail, pullet chicken, white-AA chicken, organic-AA chicken, jumbo chicken, goose and ostrich.

FROM TOP: BRIAN A JACKSON / GETTY IMAGES. BAZIL PHOTO / GETTY IMAGES. GRAPH SOURCE: THE ROYAL SOCIETY X2

GOOG INSIDE The anatomy of an egg



OUTSIDE: The shell's **cuticle** is its protective coating, blocking pores to hinder microbes and preserve freshness. An egg's **shell** forms about 9–12% of its total weight. Two **shell membranes** – inner and outer – surround the albumen and provide a barrier against bacteria.

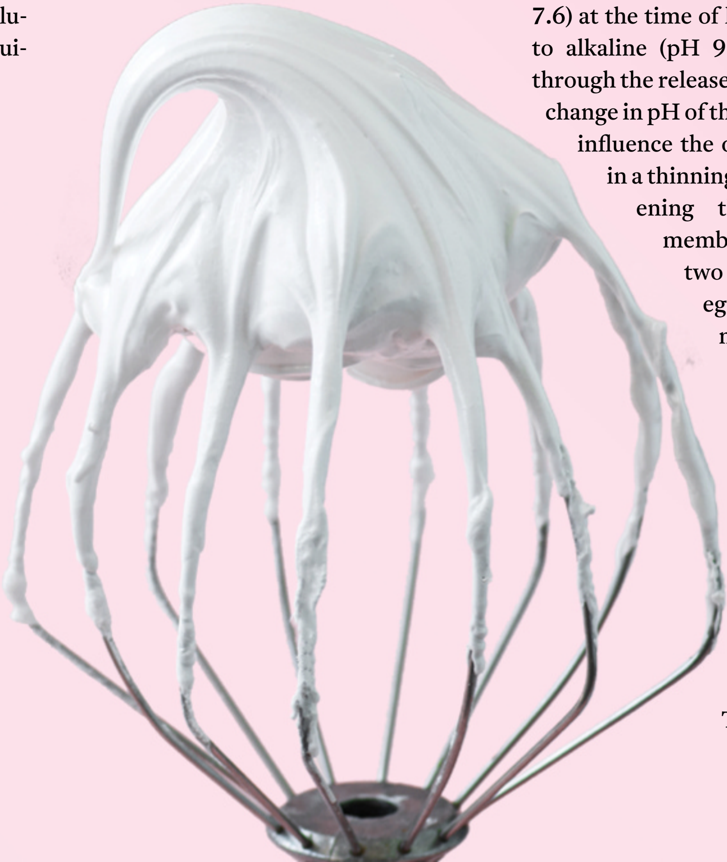
INSIDE: Fresh laid eggs are warm. As they cool, the contents contract and the inner and outer shell membranes separate to form the **air space**. The **chalazae** are ropey strands of egg white that secure the yolk. The more prominent the chalazae, the fresher the egg. The egg white, known as the **albumen**, accounts for most of an egg's liquid weight, about 67%. The white is separated from the yolk by the **chalaziferous layer** and the **vitelline membrane**. **Yolk** makes up about 33% of an egg's weight and contains all its fat and roughly half its protein. On the yolk's surface is a small spot (2–3mm across); this **blastoderm** is where the sperm enters the egg. The embryo develops from this disk, and develops in a fertilised egg in the **nucleus of pander**.

soaking eggs tends to destroy the thin protective protein layer, making it easier for bacteria to enter the shell – so if you do test an egg, cook it soon after.

The white stuff

The white of the egg (the albumen) is a solution of proteins in water. Proteins are exquisitely complicated molecular origami but can rapidly change their properties if this folding is disrupted. This is certainly true for ovalbumin, the major protein in the egg white, as it readily unfolds (known as denaturing) when shaken or whipped, as the proteins trap air bubbles. These foams can be stabilised in meringues, or function as a leavening agent in foods like biscuits, souffles and cakes.

The pH of the albumen is neutral (pH 7.6) at the time of laying, but rapidly rises to alkaline (pH 9.7) in just a few days through the release of carbon dioxide. This change in pH of the albumen is thought to influence the ovomucin gel, resulting in a thinning of the white and weakening the adhesion of the membrane to the shell. These two properties make old eggs harder to poach but much easier to peel when boiled.



Have your cake and emulsify it too

The proteins of the albumen are connected to the yolk through the chalazae, twisted bungy-cord-like structures. This shock-absorbing

WORTH THE WAIT?

Century eggs are a uniquely preserved egg, originating in China. Fresh duck eggs are coated in a paste made of lime (calcium oxide), clay, salt, wood ash (a source of alkaline salts) and strong tea. The eggs are then left for up to 100 days, depending on the alkaline concentration. The chemical treatment transforms the internal egg, with the yolk becoming a grey/green colour, and the white becoming an amber to brown gel. The change is due to the migration of hydroxide ions through the shell and membrane, which denatures and breaks down the proteins. The processed eggs have an impressive shelf life of months and are described by their flavour advocates as creamy and similar to a strong blue cheese.

FROM TOP: SAKURRA / SHUTTERSTOCK. GALIYAH ASSAN / GETTY IMAGES

scaffold helps keep the yolk centred within the egg white, with a clockwise twist at the air cell end and a counter-clockwise twist at the pointed end.

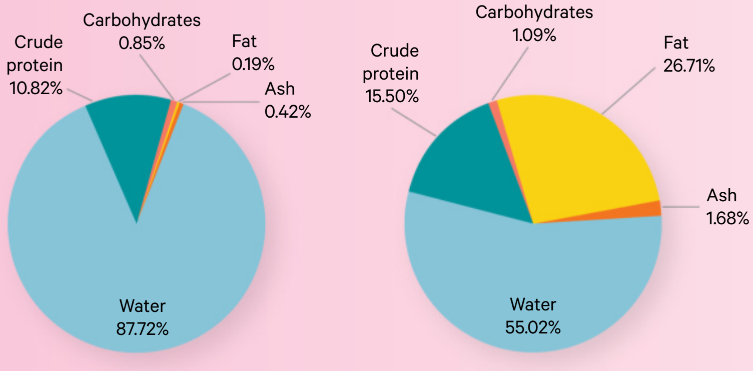
The yolk starts its development early: 3000 small ova are already present in each fluffy female chick. Once the hen reaches sexual maturity, each ovum undergoes a 10-day development prior to being released into the oviduct, where it is rapidly covered in secretions that form the egg white. Shell membrane fibres are produced and then the egg enters the shell gland, where over about 20 hours the shell is created and the pigments form on the final layers, adding colour. Finally the egg rotates, ready to be laid.

Modern breeds of chicken that lay multiple eggs in a week have many swelling ova at any one time. The yolk is made up of fat molecules closely surrounded by proteins to keep them suspended in water. "Designer" eggs fortified with vitamins and omega-3 fatty acids have been trialled, but the transfer of these nutraceuticals from feed to yolk is variable and can shorten an egg's shelf life.

One of the key culinary roles of the yolk is to stabilise emulsions. The yolk's phospholipids (sometimes referred to as lecithin) are key to this property, as they are composed of long fatty chains that are excellent at interacting with other oily molecules, and positively and negatively charged groups that can interact strongly with water.

WHAT'S BEST: HOME LAID OR COMMERCIAL? IT DEPENDS

Although free range chickens generally lay more nutritious eggs than their caged counterparts, a recent study has highlighted the potential risks of raising chickens and eating eggs in urban environments. The study examined the lead content of the urban soil, and the corresponding blood lead levels in chickens foraging on that soil, and in their eggs. The lead levels were up to 40 times higher in home garden eggs than the commercial free range equivalent, and at a level higher than the currently regulated soil lead limits. Home chicken keepers: get your soil tested!



(a)

(b)

WHAT'S IN THE BOX?

The basic components of an egg's edible parts – the white (a) and yolk (b) – are shown above. Water, protein and fat dominate. Note that yolk analysis includes both the yolk and vitelline membrane that contains it.

PIGMENT OF IMAGINATION

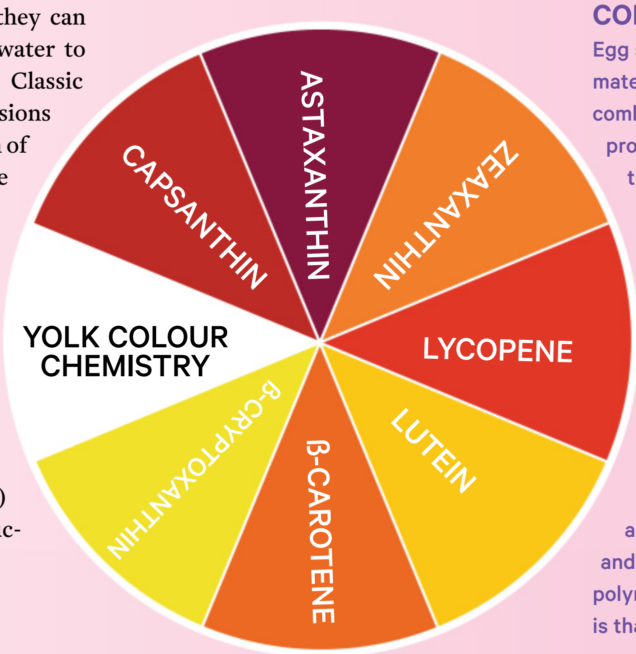
Egg pigmentation varies widely across the avian world. Chicken eggs in commercial production are normally white or brown. White eggs highlight the underlying colourless calcium carbonate of the shell, while the brown colour comes from the pigment protoporphyrin IX laid down on the surface of the egg. The brown pigment is the same molecule that's in the haem group of haemoglobin in blood, but without the iron that gives the bright red colour. It is only added at the final step of the egg-laying process, so the inside of a brown egg shell remains white. A genetic mutation in certain breeds of chicken from South America has given rise to blue coloured eggs, where a horseshoe shaped molecule called biliverdin gives a lovely pale blue colour. Unlike the surface addition of protoporphyrin IX, the blue pigment is added throughout the shell process. Chicken breeders have mixed and matched these coloured egg breeds to make all sorts of colours from blue to green to brown, including trend colours like avocado and kalamata.

TOP LEFT: WESTEND61 / GETTY IMAGES. EDIBLE EGG PART COMPOSITIONS: ANSES-CIQUAL (FRENCH AGENCY FOR FOOD, ENVIRONMENTAL AND OCCUPATIONAL HEALTH & SAFETY)

These dual properties mean they can act as a bridge between fat and water to keep them separated and stable. Classic examples of yolk-based emulsions include mayonnaise – an emulsion of oil and vinegar – and hollandaise sauce, where heated whipped yolk is used to stabilise an emulsion of butter.

Cakes also benefit from the properties of these emulsions as the phospholipids hold onto water to maintain a tender and moist crumb.

The glorious golden colour of egg yolks (colour wheel, right) comes from a combination of structurally related antioxidant compounds. These are abundant in common forage herbs, and backyard chooks confined to smaller runs can be given leafy vegetables such as silverbeet and kale to ensure their eggs display the lovely colours of lutein and zeaxanthin. Chef Dan Barber has pushed the colour of his flock's yolks to red by feeding them a massive amount of capsanthin-rich dried red pepper (no chickens were harmed). The insipid, pale appearance of cage eggs is a sign of their grain-based diet.



COMPOSITE MATERIAL

Egg shells are an example of a composite material: where two or more materials are combined to give a material with enhanced properties. You can test this by dissolving the calcium carbonate with vinegar to make a bouncy egg, or by roasting a blown egg shell to remove the proteins and make a brittle shell. Many modern materials make use of the properties of composites by taking a fibrous material and surrounding it with a solid matrix, for example fibreglass, in which glass threads strengthen plastic resins. Modern aviation requires materials that are light, strong and stiff, and composite materials of carbon fibres and irreversibly hardened thermosetting polymers are used extensively. The downside is that composite materials tend to be more expensive, and they are much more difficult to recycle at the end of their life.

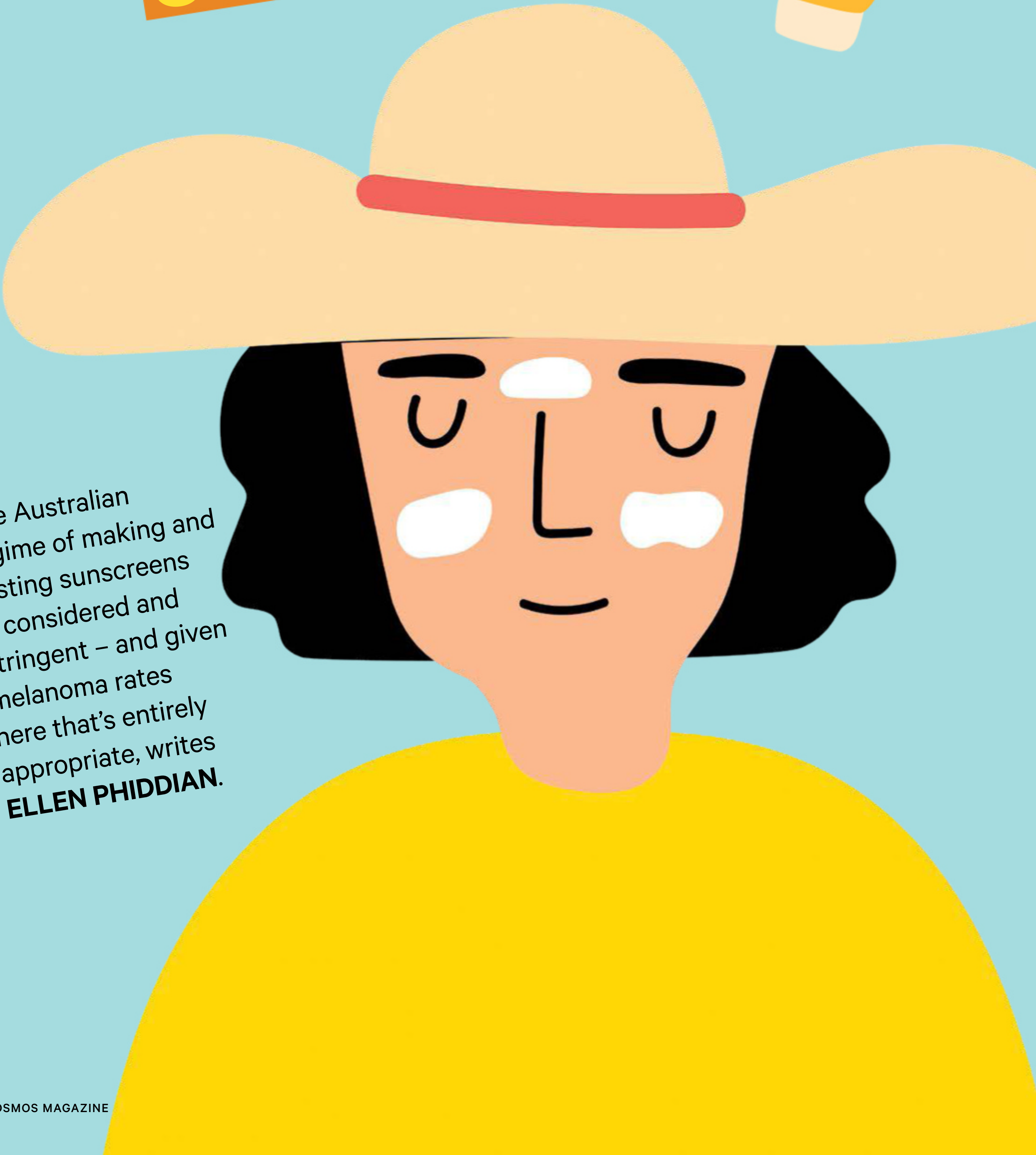
The final key transformation that eggs can undergo is gelling, where heating causes the proteins to start to coagulate. The coagulating properties are highly useful for fried or boiled eggs, or when using egg to bind hamburgers, or as an egg wash when crumbing a schnitzel.

An astonishing number of cuisines make use of eggs using an equally astonishing diversity of cooking techniques. So whenever you next poach, fry, or boil an egg, take some time to enjoy its wonderful chemistry. ◉

CLARK AND COMPANY / GETTY IMAGES

NATHAN KILAH is a senior lecturer in chemistry at the University of Tasmania. He keeps a mixed flock of chickens for their colourful eggs. His favourite way to cook fresh eggs is poached – for precisely three minutes.

WORLD'S TOUGHEST SCREEN TEST



The Australian regime of making and testing sunscreens is considered and stringent – and given melanoma rates here that's entirely appropriate, writes **ELLEN PHIDDIAN**.

Every day, you step through your front door and enter a deadly environment: the radiation out here kills hundreds of people each year, and injures many more.

It's a good thing science has provided us with a protective medicine. It's loaded with one of the dozens of chemicals that have been shown, time and again, to absorb the radiation you'll be exposed to. It's mixed into a bevy of special solvents, so that it adheres properly to your skin. A fragrance might have been added to negate the scent, or polymers to prevent water and sweat sloughing it off.

The medicine represents thousands of hours of developing, testing, and redeveloping by thousands of dedicated scientists – and more than a few human volunteers who have gotten burned to check it works.

Yes – it's sunscreen.

It should be no surprise that Australia has some of the strictest regulations on sunscreen. Along with New Zealand, we have the highest rates of melanoma in the world. A few different factors fuel the Sun's deadliness here, such as our proximity to the equator, and the fact that a big chunk of our population has pale skin. A particularly sly one is the Earth's variable distance from the Sun. In early January, Earth hits perihelion and is a mere 147 million kilometres (or so) from the star. In July, at aphelion, the planet is around five million kilometres further out. Because perihelion happens during the Southern Hemisphere summer, our sunlight is slightly more intense, making the UV radiation more dangerous.

BECAUSE PERIHELION HAPPENS DURING THE SOUTHERN HEMISPHERE SUMMER, OUR SUNLIGHT IS SLIGHTLY MORE INTENSE

Fortunately, we now have virtually limitless options for protecting our skin – from a gentle SPF 15 moisturiser that's perfect for keeping the pink off your nose as you wend your way to work, up to a fabulously sticky, water-resistant SPF 50+ that you can wear on the beach for hours. (In addition, of course, to a hat, sunnies, and beach umbrella.)

How on Earth is it all made – and how do we know it's effective?

HOW DOES SUNSCREEN WORK?

The aim of sunscreen is to shield your skin from ultraviolet (UV) light – but not visible light (unless you want to look like you're covered in paint). So all sunscreens contain at least one chemical that either absorbs or reflects UV light.

These chemicals can be metal-based (things like zinc oxide or titanium dioxide) or carbon-based (organic) molecules (such as homosalate or octocrylene. Each of them interacts a little differently with light.

“Zinc and titanium do act like mirrors,” says Dr Fabrizio Spada, Scientific Affairs Manager at Ego Pharmaceuticals, which makes SunSense sunscreen.

Zinc and titanium sit on top of the skin, largely reflecting light away (although they absorb a bit too). They reflect visible light as well, which is why they can appear white. These days, zinc and titanium particles in sunscreen are often nanometre-sized, so that they spread evenly across your skin and don't have that unsightly whitening effect.

Carbon-based filters on the other hand, absorb UV light and re-emit it as infra-red light – or heat. (This is also how melanin pigments work, and why darker-skinned people with more melanin have lower melanoma incidence.)

“Your skin might get slightly hotter as long as you stay in the UV,” says Spada.

You may have heard fuss about the differences between ‘chemical’ (carbon-based) and ‘mineral’ (metal-based) sunscreens, often accompanied by the claim that ‘mineral’ is better for you because it's ‘natural’, or it physically blocks UV instead of absorbing it. (For some reason, the fact that melanin absorbs UV, and exists naturally, doesn't seem to rate in these arguments.)

In reality, all these substances do an equally good job of protecting your skin, and none of them are better or worse for you. But, especially for those with sensitive skin, it's useful to know that we have a range of different chemicals that can do the trick: if you're allergic to one sunscreen ingredient, there are dozens more to choose from.

Check the ingredient list on a bottle of sunscreen and you'll see that ‘homosalate’ or ‘zinc oxide’ isn't the only ingredient. There'll be a bunch of other things in there, too, to keep the sunscreen stable, spread it evenly onto skin, and make it more pleasant to wear. Which brings us to…

HOW TO MAKE A SUNSCREEN

Anything that claims an SPF of more than four on its label must meet strict requirements from the Therapeutic Goods Administration (TGA) – just like paracetamol, vaccines, or any prescription drugs.

If you're making a sunscreen, you need to choose both your active ingredients (the things that block UV light) and your excipients – everything else in the mix, which help the active ingredients do their job, keep the sunscreen stable, and provide other benefits – from the TGA's pre-approved list.

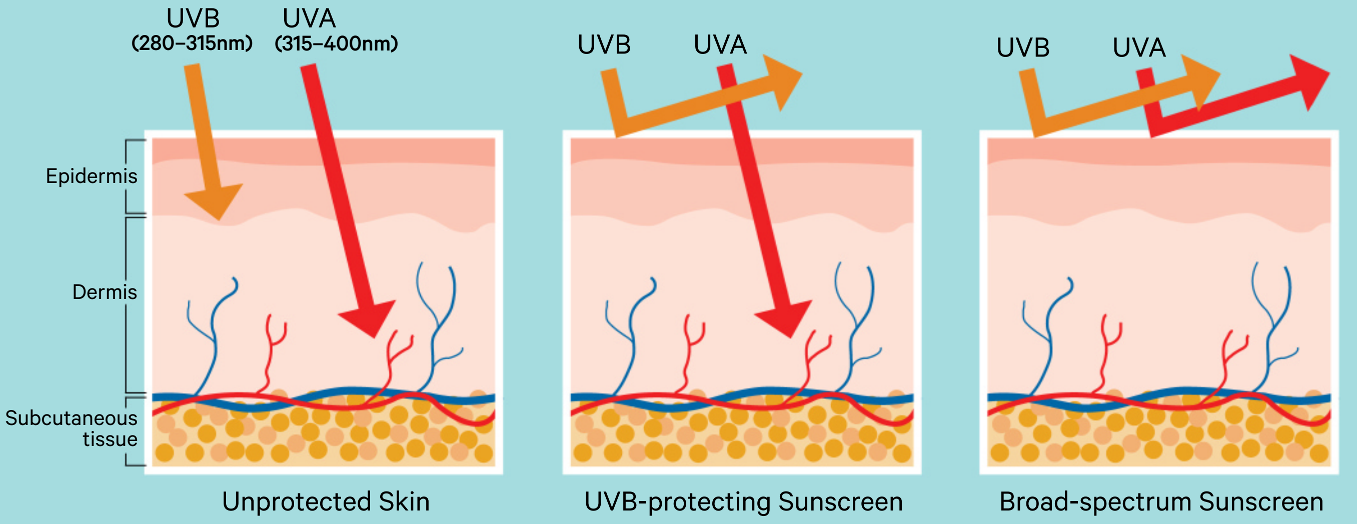
Unlike most medicines, a lot of work goes into making the sunscreen appealing. The skin-feel factor is largely decided by how the sunscreen is mixed. Sunscreens are emulsions: combinations of oily things and watery things. They can either be oil mixed into water, or water mixed into oil.

“In an oil-in-water, you will feel the water first,” explains Spada. “And that

LEFT: IGOR LEVIN / GETTY IMAGES. RIGHT: ANELIYA BEKENOVA / GETTY IMAGES

UV PENETRATION INTO SKIN LAYERS

The longer-wavelength ultraviolet A rays make up about 90% of the sunlight that hits Earth, but they can penetrate deep into the skin, causing indirect genetic damage that can lead to cancer. Shorter-wavelength ultraviolet B light affects the outer layer of our skin, also known as the epidermis, causing sunburn and DNA damage.



usually leads to lighter sunscreens, more cosmetically elegant. Whereas if you have a water-in-oil, what you feel first on your skin is the oil phase, which is usually what makes sunscreen oily, sticky, or shiny – all the things that usually don't help compliance."

Your fancy SPF 15 moisturiser is almost definitely an oil-in-water type. But, if that's the nicer version, why would you ever bother to make water-in-oils?

It's all about durability. If the mixture is designed to dissolve in water, that's what it will unhelpfully do when you go swimming, too. This is not to say that developers aren't looking for a formulation that does the trick. Spada says that an SPF 50+ oil-in-water sunscreen with four hours' water resistance has "become a bit of a holy grail".

IRONICALLY, THIS IS WHY CHILDREN – OFTEN THE LOUDEST RESISTORS OF SUNSCREEN – TEND TO GET THE STICKIEST, SMELLIEST OPTIONS.

Smell presents another challenge. Most of the odourless, or sweet-smelling, sunscreens have fragrances added to mask the scent of the active ingredients. But every ingredient adds another complication.

"The challenge is to get a fragrance that is stable when it's under the Sun, and also one that is hypoallergenic," says Spada. Any unnecessary ingredient adds another chance of triggering someone's allergies.

Ironically, this is why children – often the loudest resistors of sunscreen – tend to get the stickiest, smelliest options. Kids' sunscreen is designed to be hypoallergenic, and as powerful and water-resistant as possible.

"That's when you can deprioritise the skin feel," admits Spada. "Because, in the end, the parents are going to apply it whether the kid likes it or not."

Even the ugly whitening effect is advantageous here: it shows you where you've already applied sunscreen. (I suggest you don't share this conspiracy with any young children in your life.)

HOW TO TEST A SUNSCREEN AND THE MYSTERY OF SPF

Each bottle of sunblock you pull off a shelf represents several years of testing and trialling, adhering to strict local and international standards.

"You need to have all the evidence for safety, efficacy and quality before the product is out on the shelf," says Spada.

Tests happen both *in vitro* (in a lab-based environment) and *in vivo* – in living – organisms. In this case, people.

"If you went out into the sun in the middle of summer, and sat at a cafe for maybe 10–15 minutes without any protection, you're probably going to get a very mild pinkness to your skin," says Craig Dennyson, a business unit manager at Eurofins Dermatest, a sunscreen testing facility in Sydney.

"When we test sunscreens, we're essentially trying to replicate that."

The testing is done on volunteers: two or three for prototype sunscreens, and 10 or more when a product is close to ready for market. Volunteers have to be under 70, and can't have any medical or dermatological conditions that would complicate the test. There also needs to be a range of different skin tones among the volunteer pool: different amounts of melanin in the

LEFT: GREG BARTON. RIGHT: ANELIYA BEKENOVA / GETTY IMAGES

skin give different reactions to sunlight.

Volunteers have sunscreen applied to their lower backs, in an area that's otherwise undamaged by sun. Then, as the volunteer hangs over the back of a chair, a UV lamp shines several spots of light, each about the size of a fingernail, onto the sunscreened and un-sunscreened areas.

Testers are looking for the "minimal erythemal dose": the amount of UV that causes erythema, or skin redness. It's delicate work: Dennyson says the total area getting pinked is about the size of a Jatz cracker.

SPF, or sun protection factor, is calculated from these dots. If it took more than 50 times as much UV to get an erythema on the sunscreened skin, then the SPF is 50+. (Actually, you need your sunscreen to be 60 times stronger to earn the 50+ tag – the testing system deliberately builds in under-predictions.)

The application and the testing might be punctuated by a spa bath.

"If you're claiming four hours' water resistance, that means you have to go into the water for four hours, come out, dry off and then the product still needs to be an SPF 50+," says Dennyson.

Volunteers hang out in a very precise spa at the facility – one with temperature, acidity and flow all tightly controlled. They usually bring a book or a tablet and read or watch a movie for the duration, says Dennyson.

(Incidentally, the spa-test time factor is why Australia is one of only a few countries where you can claim four hours of water resistance on a sunscreen – most places won't allow more than 80 minutes.)

Does any of this bother the volunteers? According to Dennyson, it's a pretty mild procedure: the trickiest part is not the tiny burn, but the ability to stay perfectly still for the UV testing section. "It's not for everyone, but we've got quite a few regulars that quite enjoy it."

Following human trials, manufacturers need to prove that their sunscreen still works after sitting in a bottle for six months.

"[We test it] in incubators at different temperatures, different humidity, because you want to have a reasonable shelf life and stability," says Spada.

Should we test on people?

Human sunscreen testing has been going on since the 1980s. But is it fair to ask people to get sunburn, and expose them to higher risks of cancer? Ethics aside, the testing is expensive – even assuming you have a big group of volunteers willing to test for free (a much less likely prospect, post-COVID), it takes time and energy to recruit, support and monitor them while they soak in spas. And sunscreen profit margins are modest.

It's not a perfect system. Applying sunscreen and judging erythemal response is prone to human error – or dishonesty. In 2019, the director of a US sunscreen testing laboratory pleaded guilty to fraud after it was revealed that his company had been using far fewer test subjects than they said they were. The scandal cost sunscreen companies millions of dollars in recalls and re-tests, and prompted regulators around the world, including the TGA, to tighten their restrictions.

But scrapping human testing raises another ethical dilemma: without checking it on a person, can you guarantee that this medicine actually works?

Eurofins Dermatest are involved in several different clinical trials to reduce the reliance on human sunburns. In one, sunscreen is still spread on a person's back – but a slightly different instrument is used to shine UV light on them, and light reflection, rather than erythemal dose, is measured.

"It's virtually no exposure to UV light," says Dennyson. "They get more just walking to the station on the way to the clinic."

Another aims to dodge human skin entirely, using a robotic arm to apply a consistent spread of sunscreen onto a plastic plate. Then, UV light is shone through the plate onto a device called a spectrophotometer, and the amount that's transmitted through is measured.

"The main sticking point is that a sunscreen acts differently on your skin [than] it does on a plastic plate," says Dennyson.

To steal from Hamlet: Ay, there's the rub. Skin is a remarkably tricky thing to mimic in a lab.

"The skin has three different key layers: epidermis, dermis and hypodermis," explains Professor Vipul Bansal, director of the Sir Ian Potter NanoBioSensing facility at RMIT University. "And they support different types of cells."

Bansal's team is working on a test that uses a light-based sensor that changes colour under UV radiation. Unlike most research, which focuses on biological mimics, the RMIT team is trialling nanotechnology.

"We don't necessarily need a biologically active skin mimic – it could be a completely dead substrate, it could not contain any biological material," says Bansal. "But we have to think from the perspective of when we apply sunscreen to the human body. What kind of factors does it face?"

For sunscreen, this boils down to elasticity, absorption, texture, and – of course – light sensitivity.

Dennyson thinks that, within a few years, regulators might be allowing fewer humans in sunscreen trials in favour of *in vitro* options. But he points out that the actual amount of erythema that test subjects get is very small.

"This testing has been going on since the early '80s," he says. "It's been evaluated from a clinical ethical perspective, according to the [World Medical Association's] Declaration of Helsinki."

So, next time you're slapping on some sunscreen, spare a thought for the helpful people who spent a punishing four hours in a spa bath to check it for you – and remember, apply at least a teaspoon per limb.

ELLEN PHIDDIAN is a journalist at *Cosmos*. Her article on yawning appeared last issue.

Bond gadgets:
From reel to real

James Bond and his clever friends at MI6 have been famed over decades for their cool cars, amazing accessories and marvellous machines of land, sea and air. Here, **Matthew Agius** explains the Bond gadgets that made it into our lives (and a few we wish had).

> “You are looking at an industrial laser, which admits an extraordinary light not to be found in nature.”
>
> *Auric Goldfinger*

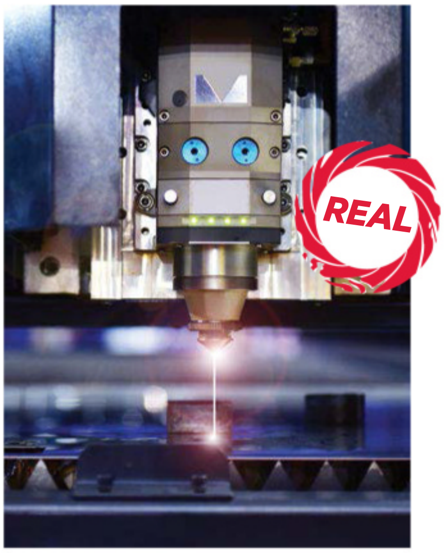
LEFT: MARTIN MALCHEV / ALAMY STOCK VECTOR. FILM STRIPS: ADOBE STOCK.
RIGHT: ADOBE STOCK. FAR RIGHT: UNITED ARTISTS / GETTY IMAGES

For 60 years, James Bond has been wielding an arsenal of amazing apparatus made by the propeller-heads at Q Branch. Bond films are known for offering a glimpse into what’s technologically possible. From nifty reuses of everyday devices to attention-grabbing one-off inventions, here are the gadgets that have gone from reel to real[ity].

Laser for gold and gland

Goldfinger

“Do you expect me to talk?” “No Mr Bond, I expect you to die!”



In this iconic scene, the villainous Auric Goldfinger (Gert Frobe) chuckles as he starts to exit the scene while Sean Connery’s Bond watches a red laser creep ominously towards his nether regions, cutting through the slab of gold to which our hero is bound.

The scene was a masterful concoction of sixties set design and visual effects. Connery was bound to a table, with a prop ‘laser’ gun slid above him. The bright red line was superimposed on the final print during post-production.

At the time of *Goldfinger*’s release, laser technology research was taking great strides, with then low-powered products. Could an international gold smuggler acquire such a weapon in the real world today?

Most definitely. Laser development has grown significantly since Bond foiled Goldfinger's plan and the technology has broad applications across industry, as Professor David Lancaster from the University of South Australia's Laser Physics and Photonics Devices Laboratory explains.

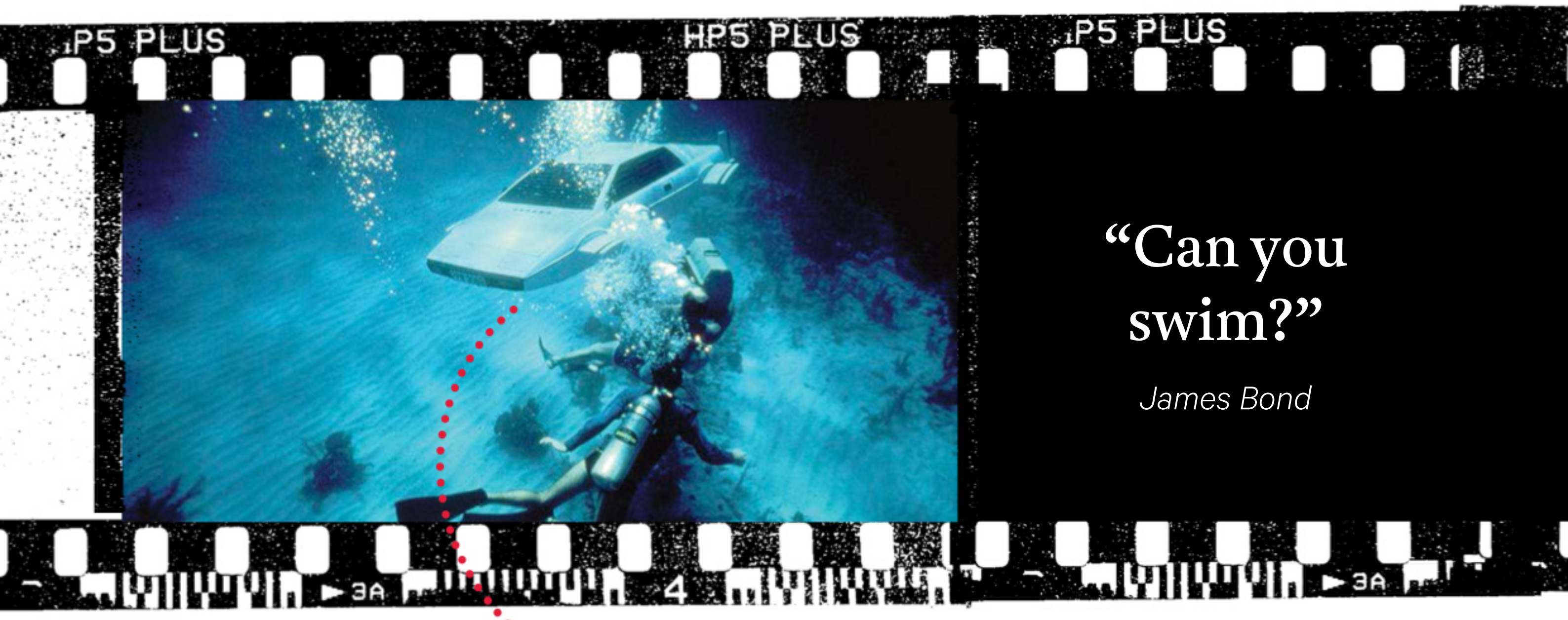
"There's been a lot of breakthroughs in how to generate laser light from electricity – things called diode lasers which are in CD players and are used in telecommunications systems and LED torches," Lancaster says. "LED torches are, really, the same technology that underpins a lot of the laser developments."

While the pointer laser that entertains your cat is about one milliwatt, modern optical fibre lasers can harness tens of kilowatts of power for precision surgery, including bladeless eye surgery, or use super-focused light beams to kill tumours.

"These fibre lasers are millions of times brighter than what you can effectively buy off the shelf now."

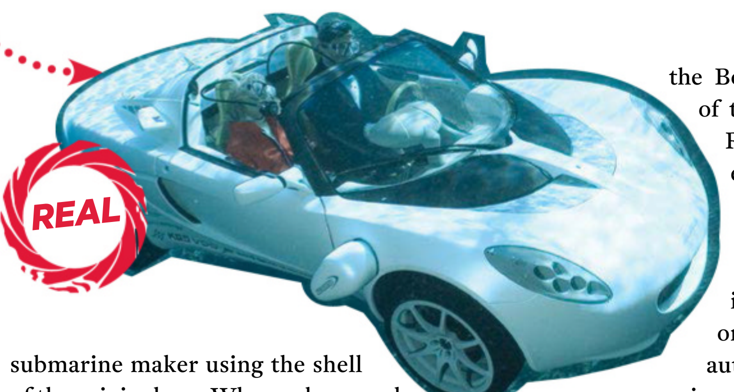
Lancaster endorses the Bond scene. "These days there are lasers that can burn metal from that sort of distance… a lot of the 3D printers are using lasers."

Even better: "It turns out they're very good for cutting and welding human organs, like eyes, for instance – using these lasers to reweld the back of your retina if you've got retinal detachment."



"Can you swim?"

James Bond



FROM LEFT: SUNSET BOULEVARD / GETTY IMAGES. RINSPEED

Submarine Car

The Spy Who Loved Me

Beset by machine-gun toting helicopters and rocket-launching sidecars? Why not drive your sleek, straight-from-the-lot Lotus Esprit off a jetty and into the ocean.

Audiences watching 1977's *The Spy Who Loved Me* would have expected Roger Moore and Barbara Bach to drown, swim to safety or – more likely – to have a tech trick up their sleeves courtesy of Q (Desmond Llewellyn). Instead, the flick of a switch transforms the Lotus into a submarine outfitted with smokescreens, mines and rockets. That vehicle – nicknamed *Wet Nellie* – was built by a Floridian submarine maker using the shell of the original car. When submerged, the sub filled with water, and required two scuba-clad pilots to operate it.

The upshot is, even though Elon Musk now owns the famous Lotus 'sub-Esprit', it wouldn't be a particularly pleasant – or convenient – vehicle to operate.

Enter Rinspeed. In 2008, the Swiss car builder launched a concept at the Geneva Motor Show: a *Spy*-inspired sub-car named 'sQuba'.

Rather than the sleek seventies lines of the Esprit, the sQuba looks more like Lotus's modern 'Elise' model – including the open top. SQuba drivers need to dress for wet weather.

"For safety reasons we have built the vehicle as an open car – so that the occupants can get out quickly in an emergency. With an enclosed cabin, opening the door might be impossible," explained Rinspeed founder Frank M Rinderknecht.

Aquatic adaptation is not where the Bond-like futurism of the sQuba ended: Rinspeed powered the vehicle with rechargeable lithium-ion batteries, and incorporated one of the earliest autonomous driving systems. With a build cost of more than $US1 million per car, it might not be such a surprise that the sQuba has never made it to market. Rinderknecht himself observed that the appeal of diving cars is probably limited to "toys for rich people".

Smart guns

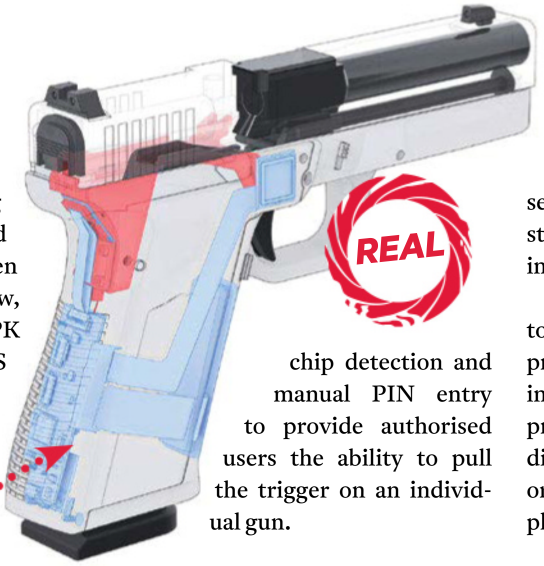
Licence to Kill

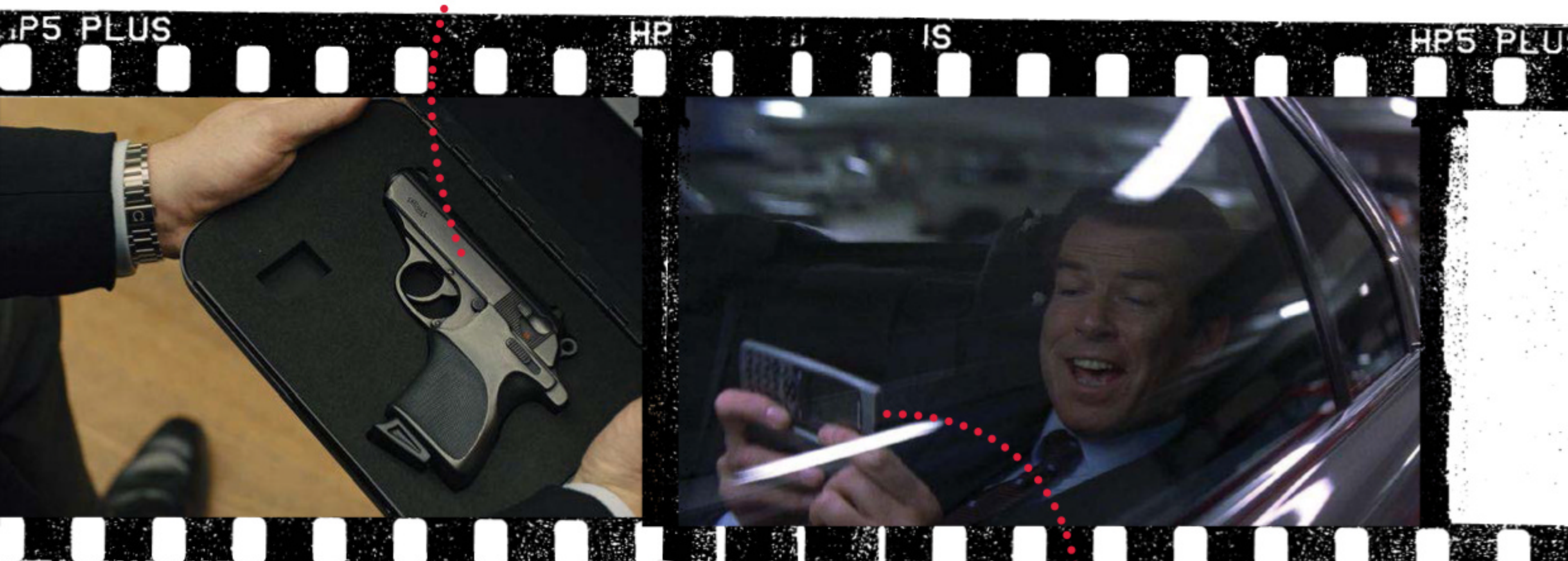
This 1989 outing gave a glimpse into firearm biometric technology when a vigilante Bond (played by Timothy Dalton) was given a handprint-reading sniper rifle. The concept was revisited in a more toned-down approach when Daniel Craig's Bond was given his new, can-only-be-used-by-you Walther PPK in 2012's *Skyfall*. Four years later, US President Barack Obama announced his push to curb gun violence with similar technology.

"If America has the technology to prevent a criminal from stealing and using your smartphone, then we should be able to prevent the wrong person from pulling a trigger on a gun," Obama said.

Some smart guns use fingerprint reading technology like those described in the next section. Others use RFID (radio frequency identification) tech. In the same way that you can tap-and-go with your RFID-equipped credit card to send payment to a merchant, smart guns use an RFID chip in a 'wearable' object, such as a watch, bracelet or ring, to beam a unique radio frequency to unlock the weapon.

In 2022, firearms manufacturer LodeStar released a 9mm smart pistol that uses inbuilt biometric sensors, radio frequency chip detection and manual PIN entry to provide authorised users the ability to pull the trigger on an individual gun.





Phone fingerprint scanning

Tomorrow Never Dies

Today, you probably have a smartphone that uses fingerprint-scan tech, but in 1997's *Tomorrow Never Dies*, the world was still getting its head around mobile phones that fit in the palm of one's hand. Pierce Brosnan's snappy Ericsson was a precursor to today's smartphones, but the fictional phone's taser-like electric shock security system, and a touchpad to remotely steer his BMW, are yet to make their way into your new device.

The fingerprint scanner allowed Bond to 'scan' other biometric readers and use the print's image on the phone screen to break into secure areas. Today's phone fingerprint scanners use a biometric reader to digitally record the pattern of your finger- or thumbprint. Biometrics are the unique physical characteristics of individuals.

When it comes to thumb- and fingerprint scanners, a reader essentially captures a 'signature' image of your fingerprint, using either light, electricity, or ultrasound. Light (or optical) scanning illuminates your print, which an imaging sensor captures in 2D and translates into digital information that's stored in your phone's memory. Every time you use the scanner again, the fresh input of your print is matched to the original signature to authenticate access.

Capacitive scanning uses electrified capacitors to create a three-dimensional

FROM LEFT: MGM / SONY PICTURES. LODESTAR. MOBILE PHONE MUSEUM.
MGM / SONY PICTURES

image of your print. Capacitive scanning ensures that every time your phone is unlocked, it's your real thumb or finger doing it, and not just a very good picture.

Ultrasonic scanning maps the highest possible resolution image of your print. Ultrasounds measure the echoes of high-frequency soundwaves directed at your body. A scan of your finger records the reflected sound directed at its ridges and valleys. This information is used to create a precise, layered image of your print.

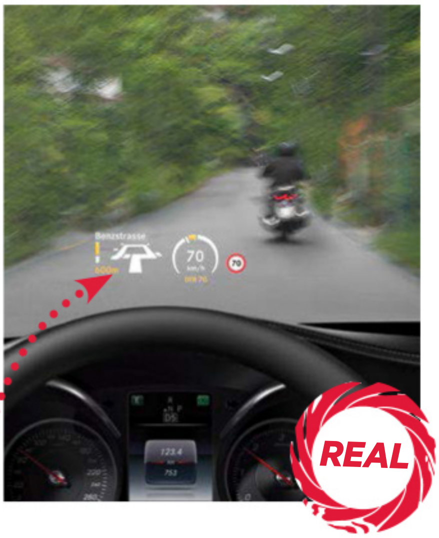
Many nations now use this technology to identify citizens at airports, while British police have (unpopularly) adopted them for 'stop and scan' identity checks.

Beyond this, *Tomorrow Never Dies* notably introduced a German-accented female voice (he *was* driving a BMW, after all) to announce to Bond each unsafe operation he performed on Hamburg roads. Today, many auto manufacturers have incorporated voice commands and responses into the consoles of their vehicles.

Heads up display

The Living Daylights

In 1987, Timothy Dalton's Bond benefitted from rocket launchers behind the front lamps of his Aston Martin Vantage V8. To pick his target, Bond flicks a switch and two targeting reticules flash onto his windscreen, zeroing on a police roadblock.



CAR SPEED 70.00 MPH TARGET TIME 2.59 SEC
SAFE DISTANCE 20 YDS AMB. TEMP. 0 C 32 F

Your car is unlikely to need the rockets, but dozens of automakers have begun incorporating heads up display – or HUD – technology into their vehicles. These HUDs project driving data onto the windscreen, including current speed and travel direction. Mercedes-Benz has even gone a step further by incorporating augmented reality experiences into its HUD – intelligently projecting directional arrows at turn points that get larger as the vehicle approaches. This technology, it's suggested, would remove the risk of drivers diverting attention from the road to check their speedometer or maps.

Laser guns

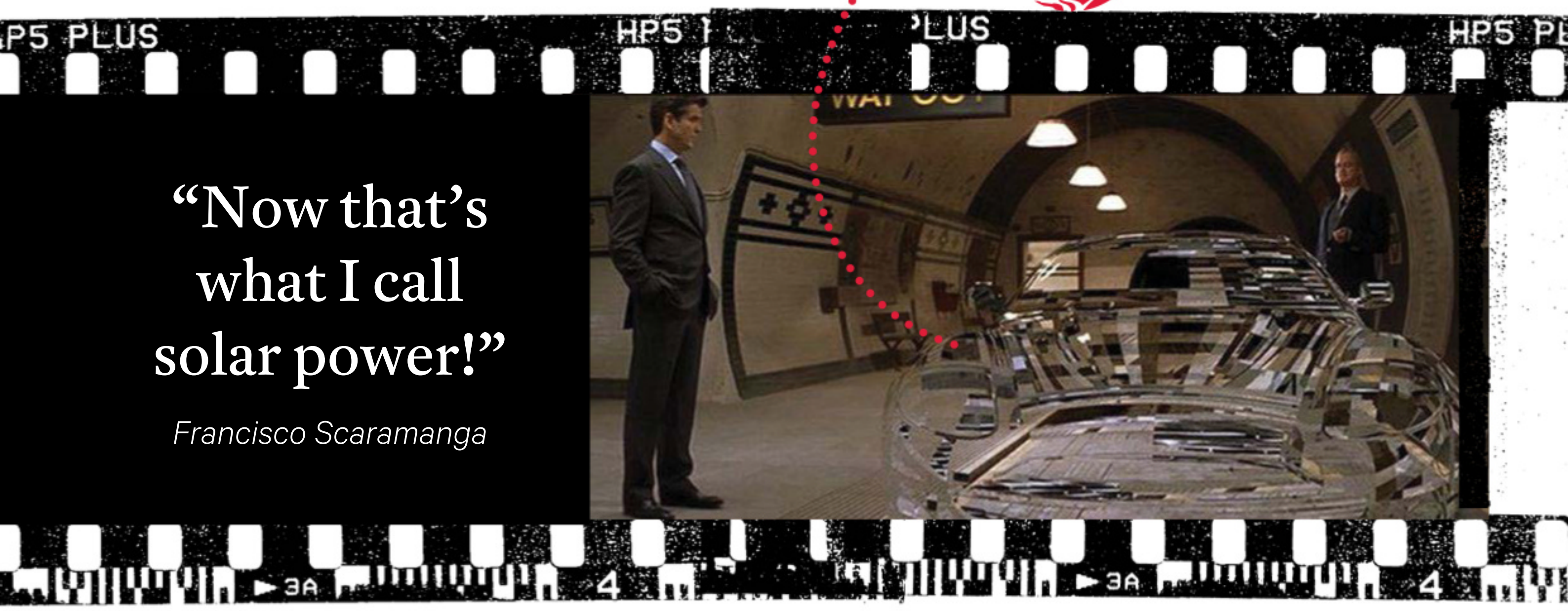
The Man With The Golden Gun

The cheerfully diabolical eyes of Christopher Lee light up as he points a large cannon-like contraption at Bond's seaplane. "This is the part I really like," he smirks, before pushing a button and blowing up Bond's escape craft.

Lee's Scaramanga has hijacked a solar energy device, which supplies the electricity to operate his laser gun. Although a hyper-rich assassin wielding such technology to let off steam might be a little farfetched, it's one of the more realistic portrayals of laser weaponry in cinema.

That's because when Lee 'activates' the gun, there's no burst of coloured laser. Instead, we hear an electronic sting and see the result: a plane exploding. Perhaps the budget for *The Man With The Golden Gun* didn't extend far enough to superimpose a

FROM LEFT: MGM / SONY PICTURES. MERCEDES BENZ. MGM / SONY PICTURES.
LEON NEAL / GETTY IMAGES



“Now that’s what I call solar power!”

Francisco Scaramanga

‘laser beam’, but the demonstration of this type of weapon is more accurate.

High-power, directed-energy weapons like the UK Ministry of Defence’s DragonFire LDEW (Laser Directed Energy Weapon) and the US military’s Laser Weapons System (LaWS) can be used to take down drones and burn out boat engines.

While the DragonFire’s first tests were completed at the Defence Science and Technology Laboratory’s Porton Down range in southern England just last October, development on LaWS began in 2010 – and it is now installed and being tested aboard the US navy’s amphibious transport dock ship USS *Portland*.

Its discharge is invisible – like Scaramanga’s fictional weapon – and costs just cents per shot to produce much the same effect as its Bond film equivalent.

“But it’s never been practical; it’s always been a technology that is just too hard, and needs rooms of PhDs to make it work,” says Lancaster. “Now, you can actually get these modules that are made commercially for manufacturing, and that’s what the US military is using.”

A key concern about using conventional weapons to bring down a drone is that firing missiles or machine guns runs the risk of damaging someone, or something, particularly sensitive. On the other hand, using a high-powered laser beam to ground a drone avoids the unnecessary hassle of loading a missile tube, or accidently blowing up a nuclear reactor.

But it’s not yet an entirely safe practice.

“One of the biggest issues with lasers, like [those portrayed] in Goldfinger… if you were doing that in real life, it would burn your eyes out within fractions of a second, because the intensity is probably like looking at a hundred suns,” says Lancaster.

“Back in those days, you could look at a laser ‘burning’, but you’re going to end up with spots in our eyes and probably wake up blind the next day.”

Invisible autos

Die Another Day

When Q (John Cleese) rolled out Brosnan’s new Aston Martin in *Die Another Day*, viewers were instead greeted with an empty platform. The ‘invisible’ car’s tech: cameras on each side of the car that projected their view to screens opposite. This plot device was mocked, but Jaguar Land Rover managed to take that idea and implement it as part of in-cabin technology in 2014. The technology used tiny cameras mounted along the external structure of the vehicle to capture its surrounds. These images were then projected to the inside cabin’s frame, providing the driver with a blindspot-free view.

BMW also made a foray into the world of invisible cars with the design of its ‘Vantablack’ BMW.

Vantablack is, currently, the darkest human-made substance. Designed for application as a satellite coating, it absorbs 99% of light, thus making objects coated with it appear as two-dimensional, black silhouettes. The safety issues of having a black spectre driving amongst us, paired with the paint’s five-figure price tag, means we’re unlikely to see it anytime soon. ◉

MATT AGIUS is a science journalist in the *Cosmos* newsroom. This is his first story for the magazine.

TOP: BMW. BOTTOM: MGM / SONY PICTURES

WHERE IN THE COSMOS?

TOP END TROPICAL SCIENCE

What better way to improve a bright Darwin day than with a little light *Cosmos* reading – as Ward Hancock demonstrates at Dudley Point, a few kilometres north of the city. We'd love to see where you're reading! Please send us a shot of your special science place: **contribute@cosmosmagazine.com**.

GUESS WHO?

QUESTION

Whose Law?

Decode where i = ♓

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HINT:

Born a nobleman, in 1820 he became a professor of physics at the University of Turin.

MIND GAMES

Who Said?

NO.23

"Asymmetry is the rhythmic expression of functional design." (10)

	1	2	3	4	5	6	7	8	9	10
I	■	1	2	■	3	4	■	■	5	■
II	6			7			■	8		9
III	10						11			
IV	12									
V	13									
VI	14									
VII	15									
VIII	16									
IX	17		■	18						
X	19		■	■		■		■	20	

INSTRUCTIONS

Answers to each of the clues in columns 1 to 10.
Row III reveals the answer.

CLUES AND COLUMNS

1 What is the study of the derivation of words? (9)
2 On mainland Australia, what mountain is 2228 metres above sea level? (10)
3 What, based on their shape, are classified as bacillus, coccus, vibrio or spirillum? (8)
4 What is a variable electrical resistor? (8)
5 Native to eastern Australia and of the family Rutaceae, which plant is either *australasius* or *banksii*? (10)
6 Which synthetic white crystalline powder is 550 times as sweet as sugar cane? (9)
7 What principle of chemistry states that if a chemical reaction occurs in stages, then the heat of each step will equal the total heat of the reaction if it had occurred in one step? (4'1,3)
8 Named after the man who re-established it, what is the main research library of the University of Oxford? (8)
9 What is one of the names of unprocessed uranium oxide which has low radioactivity? (10)
10 Which US scientist invented the polaroid camera? (5,4)

Cosmos Codeword

NO.23

20	22	19	6	21	24	14	3	■	9	15	17	17	4	17
14	■	14	■	10	■	25	■	13	■	17	■	8	■	■
25	13	20	20	17	24	16	■	26	24	19 M	17	21	24	5
13	■	20	■	■	■	24	■	22	■	13	■	16	■	15
19	13	17	20	26 S	8	15	24	19	■	26	6	24	12	17
17	■	16	■	14	■	13	■	6	■	8	■	25	■	16
16	24	16	13	25	24	16	■	8	21	17	24	15	22	■
8	■	14	■	16	■	2	■	24	■	15	■	13	■	17
■	8	13	11	14	3	17	15	19	22	■	13	6	17	11
13	■	■	■	9	■	■	■	13	■	5	■	21	■	13
18	13	16	3	14	2	24	24	8	■	13	18	22	26	19
13	■	13	■	2	■	15	■	14	■	20	■	■	■	14
2 C	13	26	26	13	23	13	■	2	24	16	1	24	14	16
10	■	13	■	16	■	8	■	■	■	10	■	15	■	17
26	6	20	14	8	■	17	7	10	14	8	13	18	20	17

Codeword requires inspired guesswork. It is a crossword without clues. Each letter of the alphabet is used and each letter has its own number. For example, 'A' might be 6 and 'G' might be 23.

Through your knowledge of the English language you will be able to break the code. We have given you three letters to get you started.

1	2	3	4	5	6	7	8	9	10	11	12	13
14	15	16	17	18	19	20	21	22	23	24	25	26

ALL PUZZLES DESIGNED
AND COMPILED BY
SNODGER.COM.AU

It Figures

NO.23

	1	2	3	4
A				
B				
C				
D				

INSTRUCTIONS

Using the clues below place the numbers 1 to 16 correctly in the grid. How many clues do you need?

LEVEL 1 – CHIEF SCIENTIST

1 The first number in each row is the average of that row.
2 Column 2 contains only factors of 16.
3 The square number in the top left is the only number in a corner which isn't a multiple of 5.
4 The numbers in Row C are all factors of 12.
5 The sum of the three prime numbers beginning Column 4 is 20.

LEVEL 2 – SENIOR ANALYST

6 The product of the numbers in Row C is 36.
7 All the multiples of 7 are in the same column.

LEVEL 3 – LAB ASSISTANT

8 The sum of the numbers in Row A is 36.

SOLUTIONS: COSMOS 96

CODEWORD

P	A	R	A	S	I	T	E	■	Q	U	A	R	T	Z
R	■	A	■	T	■	R	■	D	■	N	■	U	■	E
E	P	I	T	O	M	E	■	R	E	E	D	I	E	R
D	■	N	■	N	■	K	■	O	■	Q	■	N	■	O
A	L	W	A	Y	S	■	J	U	G	U	L	A	R	■
T	■	A	■	■	■	B	■	G	■	A	■	T	■	A
O	S	T	E	O	P	A	T	H	■	L	Y	I	N	G
R	■	E	■	B	■	N	■	T	■	■	■	O	■	R
■	B	R	A	V	A	D	O	■	N	U	A	N	C	E
A	■	■	■	I	■	I	■	F	■	R	■	■	■	E
M	I	S	C	O	N	C	E	I	V	E	■	F	A	D
P	■	C	■	U	■	O	■	X	■	T	■	A	■	■
E	A	R	■	S	T	O	M	A	C	H	A	C	H	E
R	■	U	■	L	■	T	■	T	■	R	■	E	■	N
E	M	B	R	Y	O	■	R	E	D	A	C	T	E	D

1 U	2 Y	3 X	4 G	5 O	6 W	7 I	8 L	9 P	10 N	11 E	12 J	13 M
14 A	15 Z	16 T	17 F	18 H	19 D	20 V	21 B	22 C	23 Q	24 R	25 S	26 K

IT FIGURES

16	11	13	15
4	12	6	3
8	9	10	5
2	7	14	1

WHO SAID?

Edith Widder

A US oceanographer, marine biologist and author, Edith Widder is the co-founder, CEO and Senior Scientist at the Ocean Research & Conservation Association.

■	T	■	O	■	S	C	■	E	■	E
A	E	■	O	S	T	I	C	L	G	U
C	T	A	L	U	R	R	A	E	R	B
E	R	L	O	T	E	R	M	C	E	A
T	A	L	G	T	H	H	B	T	A	C
Y	H	U	I	O	L	O	R	R	T	T
L	E	V	S	N	O	S	I	O	B	E
E	D	I	T	H	W	I	D	D	E	R
N	R	A	■	O	■	S	G	E	A	I
E	A	L	■	O	■	■	E	■	R	A

WHOSE LAW? ANSWER:

At the time when any given stratum was being formed, all the matter resting upon it was fluid, and, therefore, at the time when the lower stratum was being formed, none of the upper strata existed. *Nicolas Steno*

Natalie Robson

MARINE SCIENTIST

When Natalie Robson began diving with turtles in Top End waters she was a little nervous: saltwater crocodiles and box jellyfish were hazards she had not encountered growing up around Perth. Sharks yes, but not crocodiles.

"My family is very science-based and my dad was a sailor and surfer and I learnt to dive with my sister when we were at high school; as a child I played in rock pools and dived around reefs. I loved trying to figure out how it all worked and enjoyed looking at the world from a different perspective. I decided to be a marine scientist when I was 10 years old."

After graduating with honours from the University of Western Australia, Natalie applied for every marine science position imaginable and landed a dream job designed to protect green and hawksbill turtles, at the Conflict Islands in Papua New Guinea.

"I really enjoyed my time in PNG," she says. "I helped set up a ranger program which gave me awareness of local people, their culture and their country. I was keen to work with rangers as I think indigenous knowledge is very important.

"To do a PhD, it had to be the perfect project – somewhere I could utilise my own ideas and enjoy the scope of the work. I find turtles to be interesting animals; they are ancient creatures and are very important culturally as a food source in northern Australia."

Natalie was recruited by Charles Darwin University for an ARC linkage project focusing on the habitat use and genetics of foraging green turtles across the northernmost parts of the NT.

"I didn't think I would get in the water as much in the NT, but there are many beautiful coral reefs and clear water," she says. "We are very aware of crocs and stingers. We dress to protect ourselves from jellyfish and have someone on the boat looking out for crocs at all times.

> **"We dress to protect ourselves from jellyfish and have someone on the boat looking out for crocs at all times."**

"It was quite an adjustment from sharks to crocs and I was pretty nervous to start with – but you get to know the area you're working in. I think crocs are more dangerous than sharks, because they are more territorial. Sharks are usually just hungry."

Natalie finishes her PhD in March 2025. "I'm not sure what I will do next," she says. "There's a lot of work still to be done in the marine environment up here and a lot of gaps in knowledge, especially outside of Darwin Harbour."

READ MORE ABOUT THE MARINE ECOSYSTEM OF WESSEL ISLANDS ON PAGE 64.

DAVID HANCOCK

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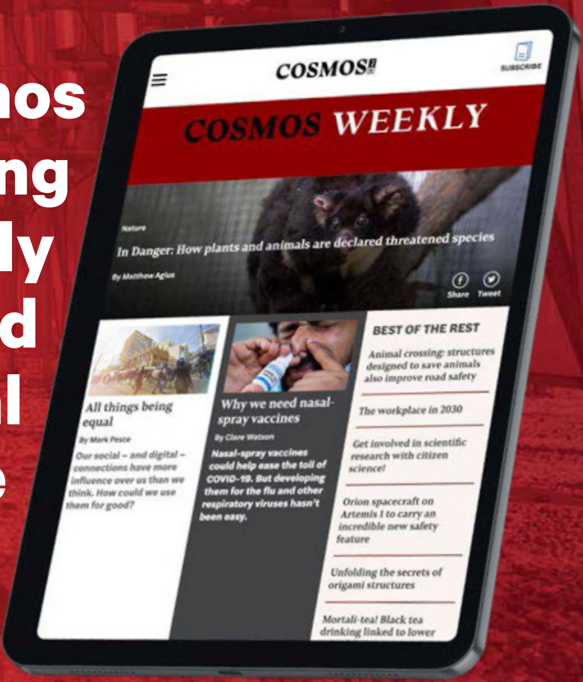

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